NUCLEONICS

August 1952

Radiation complicates even the use of tweezers. At Mound Laboratory, remotely operated tweezers are viewed through a split-image periscope which shows side and top views simultaneously (see p. 14)

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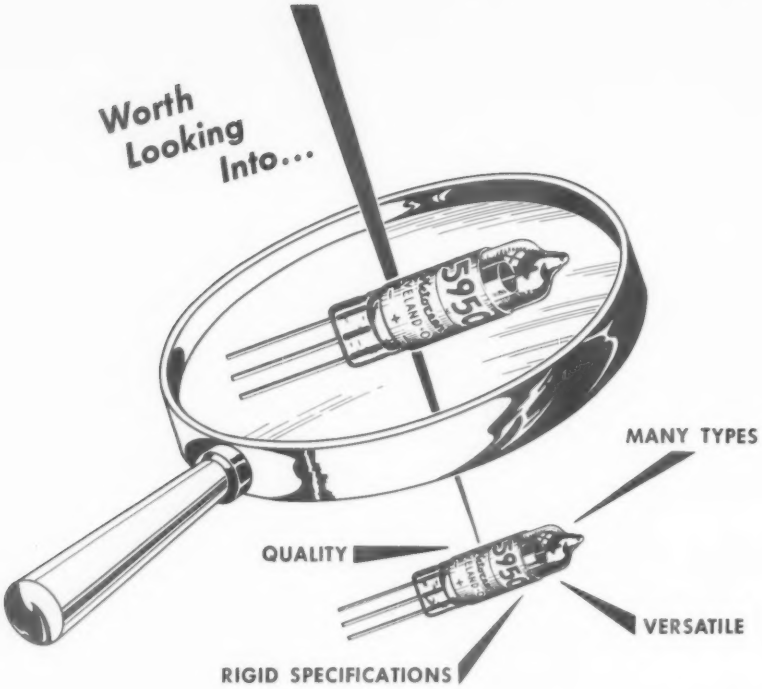

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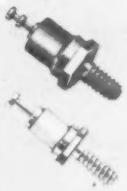

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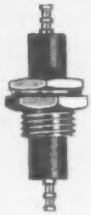

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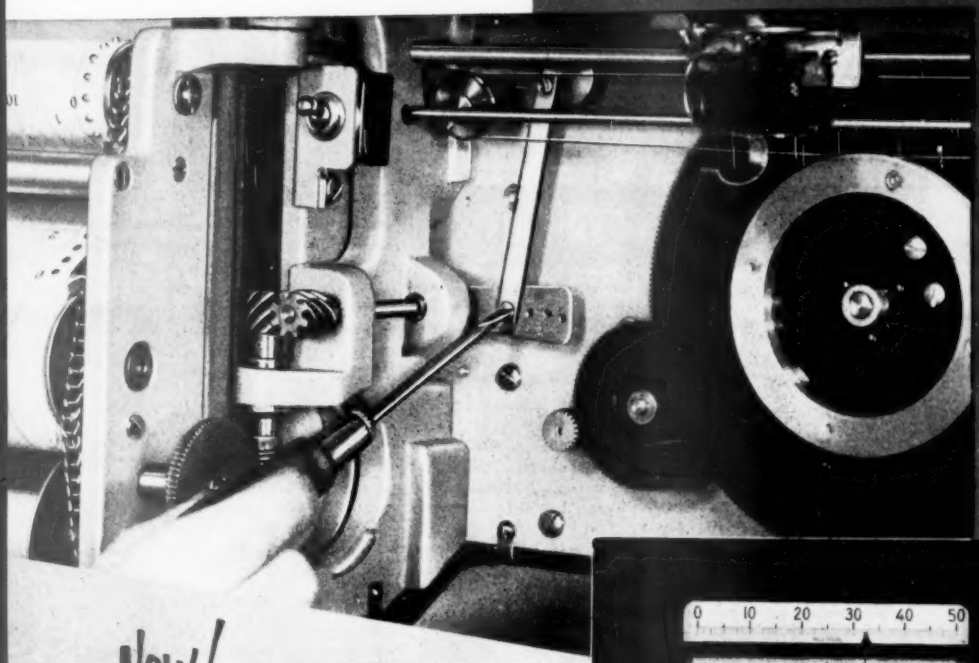

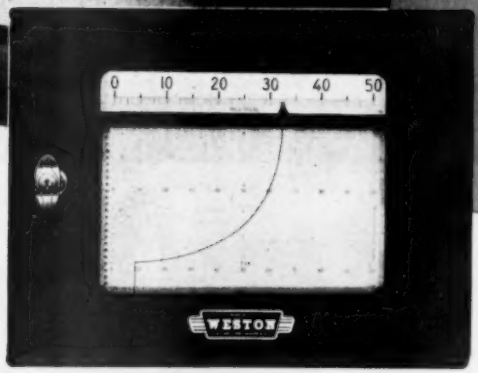

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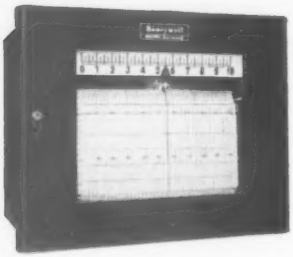

The *ElectroniK* Narrow Span Potentiometer —a completely self-contained recorder with built-in high gain amplifier—now makes it possible to measure, record and control extremely low level d-c voltages. Available as a strip chart recorder (illustrated), multi-point precision indicator, and as a circular chart recorder with pneumatic control.

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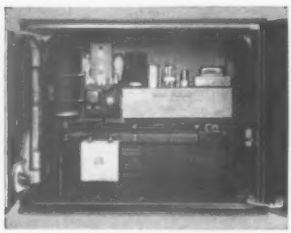
Limit of error....½% of span.
Stability.....(after warm up) 1 microvolt or less.
Dead Zone.....0.1 microvolt or 0.006% of range (whichever is greater).
Pen Speed.....24 or 12 seconds full scale travel.
Range of Input Signal to Recorder...(approx.) 0.05 microvolt to 1 mv.

for rapidly changing variables...



Interior view with chassis swung out, showing amplifier and damping circuit components.

The *ElectroniK* High Speed Recorder follows fast variations in the measured variable with unusual accuracy. Its recording pen can travel across the full 11-inch chart *in only one second*. Can measure any d-c signal . . . from thermocouple, *Radiamatic* radiation element, pressure and force transducer or other sensing element.

ELECTRICAL CHARACTERISTICS

Pen speed.....(nominal) full scale travel in one second, maximum.
Accuracy.....0.25% of span (ranges over 12 mv); 0.030 mv (ranges under 12 mv).
Dead Zone.....0.06% of span (ranges over 12 mv); 0.007 mv (ranges under 12 mv).
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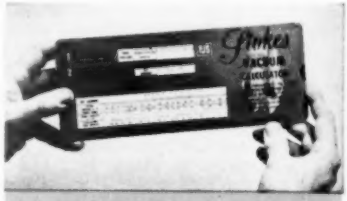

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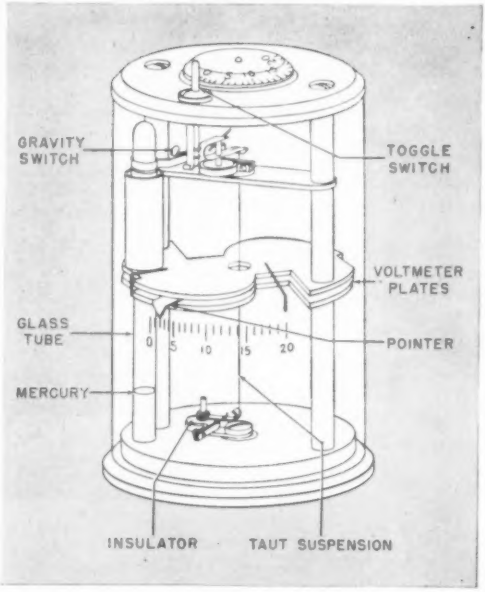

CUTAWAY VIEW of monitor shows operating parts. Self-charging gravity switch is operated by inverting the monitor.

NUCLEONICS

AUGUST, 1952

At the Crossroads

FLIGHT at a speed of 1,238 miles per hour—nearly twice the speed of sound—and a crossing of the Atlantic Ocean in a little more than three days made front pages last month. These two records provide further evidence of the fact that physical separation of continents is becoming more and more meaningless.

In addition, the economic interdependence of the nations of the world was brought home strikingly last month in the report by the President's Materials Policy Commission. "The destinies of the United States and the rest of the free world are inextricably bound together," the report said. "If the United States is to increase its imports of materials it must return in other forms strength for strength to match what it receives."

ONE volume of this five-volume report was devoted to an analysis of the energy resources and needs of this country and the rest of the world. By 1975 roughly twice the 1950 supply of fuels and electricity will be needed. "The time will come (in the not-too-distant future) when civilization's energy needs will outrun nature's declining store of fossil fuels available for economic use. Before this happens, ways must be found to harness economically such unconventional sources as solar and atomic energy."

"In the urgency of today's disordered world," said the report, "there is less and less chance that what is casual will be adequate. . . A tremendous amount of nuclear research is under way, but much more is necessary before any definitive picture can be drawn. Even from our present knowledge, it becomes evident that atomic energy will some day become a very important factor in the economy of the world."

The international significance of atomic energy was also pointed up by a Monsanto Chemical Co. executive last month. Atomic energy "will be useful in our own country," he said, but "can be even more helpful in developing the resources of all the free nations of the world." As far as a "point 4" program is concerned, nuclear power is the "greatest tool for contributing materially to the economic development of other nations."

WHAT can be done to implement the needs and principles expressed in the foregoing? As far as atomic energy is concerned, we are now at the crossroads. The technical feasibility of producing electric power from a nuclear reactor has been verified. Much technological development is still required, however, before nuclear power can stand on its own feet economically. But strong interest exists in carrying out this development.

What is needed is a vigorous Government-industry effort. In addition to the industrial nuclear power study program which has been going on for the last year, a complementary effort by AEC is needed—for two reasons—because of the major technical problems yet faced and because of the considerable initial investments required.

AEC's files are filled with "blueprints of promising models" of nuclear power reactors, according to Rep. Jackson of the Joint Congressional Committee on Atomic Energy (see p. 72). Jackson says AEC should spend $30–40-million and build a power reactor by 1954.

MONSANTO feels the financial and legal obstacles are too great right now for it to spend its own money (see p. 74). It wants AEC to build a pilot plant—an idea not at all incompatible with Jackson's idea.

The legal problems bothering Monsanto are the same ones that are causing other companies interested in nuclear power to balk. The Atomic Energy Act of 1946 restricts to the Government ownership of plants (power reactors here) capable of producing fissionable material and prohibits patenting of inventions useful in the production of fissionable material. Since many of the circumstances surrounding the inclusion of these limitations in the original law have changed, amendments to the Act should be considered. In addition to an aggressive development program, positive encouragement must be given to industry. —*J.D.L.*

Joint Committee on Atomic Energy

—A New Experiment in Government

One of three statutory committees, this 18-man body was set up to represent Congress and the American people in overseeing the Nation's atomic enterprise. Its members work in secrecy and make frequent visits to AEC sites in their continuing studies of atomic energy problems

By REP. HENRY M. JACKSON
Member, Joint Congressional Committee on Atomic Energy
Washington, D. C.

WHO RUNS the nation's atomic energy business? My colleagues and I on the Congressional watchdog committee have sometimes been accused of running it ourselves. We have equally been accused of being mere captives of the Atomic Energy Commission, which administers the McMahon control law enacted six years ago. In reality, I think, the relationship between committee and commission—and therefore between Congress and the Executive Branch—is almost as unique as atomic energy itself.

The founding fathers did not foresee such a relationship, and present-day students of our Constitution seem almost unaware of its growth. In considerable degree both committee and commission jointly run the atomic program. Basic commission policy decisions tend to be made with the advice and consent of our committee.

So far as the law itself reads, we on the committee are entitled to be "fully and currently informed." At first glance this might seem a frail foundation for committee authority—merely the right to know, with no legal jurisdiction whatever to direct or to supervise. Yet, in the atomic energy business, this simple right to know the highly secret facts in and of itself confers immense powers of moral suasion. Here, in a most literal sense, knowledge is power.

Operates in Secrecy

The ordinary government agency functions in a glare of publicity. The people themselves, through the sheer force of their opinion, often shape policy. But a curtain of secrecy covers the world of atomic energy. A fully informed public opinion does not and cannot exist. Five commissioners, whose only tangible link with the electorate is their appointment by the President and their confirmation by the Senate, are required to make decisions that affect not merely our hopes for material advancement but also our very national survival. The commissioners are required to award contracts and select construction sites and spend hundreds of millions of dollars.

It is no wonder that Congress created its own watchdog committee, vesting that committee with the right of access to all the facts and the moral duty to speak out if and when an alarm needs to be sounded. Thus far the committee members, as a group, have not felt that any action or failure to act on the part of the commission called for united clarion protests. In the fall of 1949, when some responsible officials recommended against a major attempt to build the hydrogen bomb, the committee would have issued solemn warnings if any such recommendation had been followed. Likewise, at times when the military have been slow to

recognize opportunities for building stronger defenses at less cost through atomic weapons, the committee would have declared its views in no uncertain terms had the end decisions so required.

If powerful and unanimous protests ever were to issue from the committee, I presume they would be heard and considered in every corner of our land; for the committee serves as the only substitute for public opinion, the sole conduit for transmitting what in a normal and nonsecret operation might be the popular will. The commission has therefore come to consult more and more closely with my colleagues and myself on the committee and to take our views into account.

But such consultation creates a dilemma for the committee. Since, from a strict legal viewpoint, we have only the right to be "fully and currently informed," should we simply accept the information furnished us and express no opinion concerning it—even though we fear the commission and the Defense Department may be on the brink of making a serious mistake? Or should we ourselves take a position before a far-reaching issue is decided, thus assuming—at least in a moral sense—part of the responsibility for the consequences?

Role of Committee

Let me ask the question in specific ways. Should we on the committee urge the building of certain plants which we feel, in the interests of national security, need to be built? We have in fact brought such pressure. Should we on the committee have access to the confidential FBI reports on atomic employees? We do in fact have such access—the only committee of Congress that does. Should our committee insist upon seeing the internal staff papers of the commission and the minutes of commission meetings? We have never so insisted because we respect the commission's need for a certain privacy in its internal functioning. Should we be informed of commission decisions before they are reached or only afterward? In fact we know about the big issues far in advance of any solution, but on lesser matters we are sometimes advised after a decision is made.

What about the award of contracts? What about the hiring of personnel and the selection of plant sites? Should we on the committee intervene in these matters? In fact we do not intervene. We have followed a strictly hands-off policy—and rightly so.

Let me cite some real-life examples well-known to members of the committee. A few years ago many technical people told us that the supply of uranium raw materials is rigidly limited. As laymen we knew that in the case of copper and in the case of iron and gold and sulphur or just about any raw material you care to name, a greater exploration and mining effort pays off in greater production. We also knew as laymen that uranium is plentiful in the earth. Therefore, the technical people to the contrary notwithstanding, we concluded that our country could get uranium in far greater quantities if it wanted to pay the necessary price—and this is so.

Again a few years ago many experts told us that the A-bomb could not be carried on a fighter plane—that the bomb just could not be made small enough or light enough. Again as laymen we knew of no piece of ordnance equipment that could not be refined and improved and reduced in size. Some of us therefore urged that atomic weapons be adapted to tactical uses.

To cite yet another example, certain high-ranking military men gave us to understand that we were building enough atomic weapons to defend our country. Once more, no member of the joint committee had attended West Point, but we saw that our country would need and could profitably use, if attacked, this weapon in huge numbers—indeed, that there is no such thing as having "enough" atomic bombs.

H-Bomb Decision

In late 1949, when there was the controversy on the question of whether or not we should really try to build the hydrogen weapon, a very influential group of experts argued against this step. First they said it would be immoral. Then they said, even if making it in self-defense were moral, it could not be built. Then they said, even if it could be built, it could not be delivered. Then they said, even if it could be delivered, it would cost too much. Then they said, even if it would not cost too much, it could do nothing that A-bombs couldn't do.

The members of the joint committee were fully sympathetic with the emotions that obscured the logic of these experts. We, too, were horrified at the thought of H-bombs. But there was one thought that horrified us still more—the thought of H-bombs exclusively in Soviet hands. We felt, as realists, that we had utterly no choice except to insist that our own nation's hydrogen program go forward.

One fact stands out, nonetheless. The joint committee simply does not conform to what I conceive of as the customary stereotype of a Congressional committee. Most people think of legislative committees as veto groups—as bodies whose overriding concern is holding the Executive Branch in check and preventing capricious or ill-advised acts. This is of course one of the vital jobs of the joint committee, and we perform it as best we can. More often than not, however, we find ourselves saying to the Executive Branch *not*: "Do less; do it less rapidly," but, "Do more; do it more boldly." And for every time we ask, "Isn't this program too ambitious?" we find ourselves asking a dozen times: "Isn't this program too cautious?"

International Control

In addition to its interest in military and peacetime applications of the atom, the joint committee closely follows the continuing quest for effective international control of atomic energy. As the stacks of atomic weapons pile higher and higher on both sides of the Iron Curtain, and as we contemplate the prospect of a hydrogen armaments race, the need for foolproof regulation of these hideous weapons—and all other weapons as well—grows more and more urgent.

Atomic energy is the most important single factor conditioning our lives in this twentieth century. I am confident that our children will look back on our present day atomic reactors, with all their exquisite gadgetry, and they will find themselves wondering how such primitive machines ever worked. And above all, I deeply believe, our children will look back upon today and wonder how some learned men could have been so insensitive to the onward sweep of technology as to depreciate the promise of atomic energy.

* * *

This article is based on a talk at Ann Arbor, Mich., before the University of Michigan Law School conference on atomic energy, June 28, 1952.

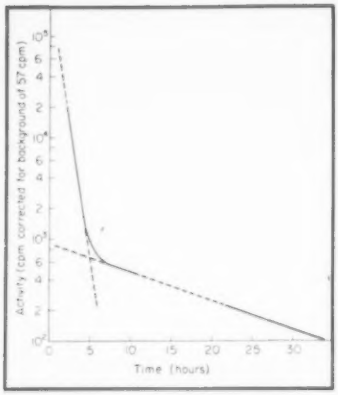

FIG. 1. Decay curve of natural radioactivity of precipitation collected at Helena, Montana

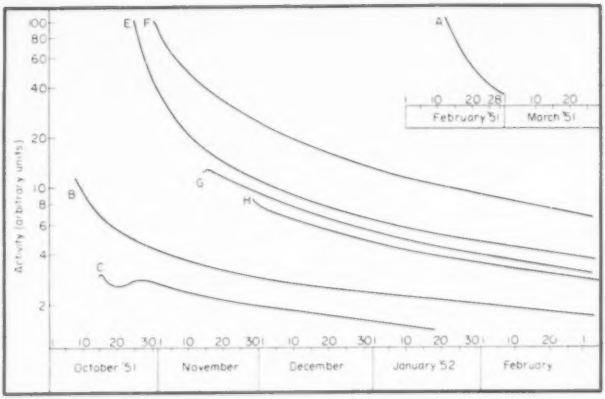

FIG. 2. Decay curves of samples of atmospheric radioactivity listed in Table 1

Tracing Nuclear Explosions

High atmospheric radioactivity is not necessarily caused by a nuclear explosion. But the decay rate of this activity will tell if it is caused by fission products, and the date of fission can be approximated by comparison with a known decay curve

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MEASUREMENTS on snow and rain samples at this laboratory confirm the observation of Meinke (*1*) for snow at Ann Arbor, Michigan, of the wide geographical spread of fission products from the Nevada nuclear explosions of January–February, 1951. Fission products were also detected here during October and November, 1951, some of which must have originated in a foreign country and others of which originated either in Nevada or a foreign country.

High radioactivity, per se, is not adequate evidence for the presence of fission products, particularly in regions which are high in natural radioactivity. Fission products may contribute less activity to a precipitation sample than already present from normal atmospheric radioactivity and so must be identified by other characteristics.

The procedure used in this laboratory, different from Meinke's, is based on properties unique to mixed fission products, and suggests a method for calculating the date of origin of such products, i.e., the date of the explosion which produced them. Practical use of this dating method however, without access to classified information, is contingent upon the validity of what can only be assumptions at this time.

Natural Atmospheric Activity

For over two years an automatic 24-hr daily record of atmospheric radioactivity has been taken as part of a project to investigate the feasibility of remotely locating large natural uranium and/or thorium deposits by correlating changes in local activity with wind and other meteorological data. Concentrated rain and snow samples have also been measured from

time to time to determine normal conditions in more detail. Such samples were prepared principally by filtering rain or melted snow through cotton and using the cotton or the evaporated filtrate, or by evaporating to dryness without filtering. The samples usually were measured with a shielded end-window counter under reproducible geometrical conditions.

Normal radioactivity of fresh snow has been observed before (*2, 3, 4*), but it is not generally realized what high values can be obtained from precipitation samples in some localities. Figure 1 is an example of a decay curve from a sample prepared by rapidly melting snow which fell here on May 2, 1950, and filtering 16.1 liters through cotton which was dried and suitably mounted for counting. By extrapolating the initial counting rate of 21,800 cpm back to the effective time of snowfall (about 1.2 hr on abscissa of Fig. 1) this becomes 54,000 cpm. Correction for counting geometry (30%) increases this to 180,000 cpm; without trying to correct for absorption loss in sample or counter this is a count of over 3,100 times background (57 cpm) for this total sample. This is a conservative lower limit resulting from neglecting the activity of the filtrate which, based on later samples, contained more activity than was filtered out.

In spite of this high value of activity, it is considered to have arisen only from natural sources. The steeper initial part of the curve arises from the activities of various decay products of radon and thoron, the later part resulting from thoron products with the decay rate governed by the 10.6-hr half-life of $_{82}Pb^{212}$. Moreover, the most recent known prior nuclear explosion occurred more than eight months previously; this was the first Russian atomic bomb, as announced by the White House on September 23, 1949.

The press reported numerous instances of radioactive snow in various parts of the country following the various Nevada tests, the presumption being that the Nevada tests were responsible. However, it appears likely from these considerations that normal activity could have been responsible.

Anomalous Atmospheric Activity

Various precipitation samples were prepared during the year 1951, and eight of them had radioactivity decay characteristics which represented a distinct and significant departure from the decay curve for normal atmospheric activity. (Not all local precipitation was measured during the year and some anomalous radioactivity was probably present sometimes in the absence of precipitation.) Figure 2 shows the decay of seven of the eight samples which are further described in Table 1. (Sample *D* was not plotted because it was followed for only a relatively short interval.)

Most of the information of Table 1 is self-explanatory. The data of columns 7, 8, and 9 are useful in roughly comparing the relative intensities of the various samples plotted in Fig. 2. In Fig. 2 the curves are all adjusted for convenient presentation on one chart

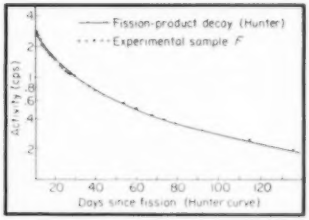

FIG. 3. Comparison of decay curve for fission products from reference 7 and data for one sample of atmospheric radioactivity

and so are not necessarily in the order of initial intensity. The comparison is approximate because measurements were not always begun at the same interval after the occurrence of precipitation. Furthermore, it is difficult to compare the initial activities with that of samples of normal activity since extrapolation of the curves (of changing curvature) back to the time of precipitation introduces inaccuracies.

Comparing Fig. 1 and any of the curves of Fig. 2, one can see that normal activity, as collected here, has a maximum half-life of 10.6 hr, whereas all of the decay curves of Fig. 2 show an initial "instantaneous half-life" from about 3 to 28 days and an increase in these values with time. (See last column of Table 1). The "instantaneous half-life" is here defined as the half-life calculated from the tangent to the decay curve at any point. Duplicate samples prepared from the same precipitation in several cases confirm the general results shown by Fig. 2. In contrast to the simple exponential character of Fig. 1, Fig. 2 shows curves which are predominantly concave upward on a semi-log plot, so that these samples not only contained some unusually long-lived activities but contained a sufficient number of radioisotopes of various half-lives to produce these net decay curves.

Fission Origin of Activity

There being no natural source for atmospheric materials with decay characteristics such as those just discussed, and since mixed fission products do have such characteristics, it is concluded that the precipitation which occurred on the dates given in the third column of Table 1 each contained products of a nuclear explosion or other fission reaction.

Table 2 summarizes the various test explosions conducted by the U. S. Atomic Energy Commission during 1951 and the Russian nuclear explosions announced by President Truman in 1951.

In addition to the tests given in Table 2, but probably not involved in any of the precipitation of Table 1, the first Russian explosion was announced as occurring prior to September 23, 1949, and AEC tests were conducted at Eniwetok in the spring of 1948. Prior to that there were the two Bikini nuclear detonations of July 1946, the bombing of Hiroshima and Nagasaki in August, 1945, and the New Mexico explosion of July, 1945.

Comparison of the dates in Tables 1 and 2, make it apparent that the fission products of sample *A* originated in Nevada, simply because there was no other known source at that time. It is further concluded that the fission products of samples *B*, *C*, and *D* probably originated outside the United States because the corresponding precipitation took place prior to the first Nevada explosion of the October–November series and well after the last explosion of the January–February and May series. The remaining samples of Table 1 may have originated either in Nevada or outside the United States. Further delineation would probably be possible by detailed meteorological analyses.

It can be said that the fission products of sample *A*, originating in Nevada, took at least five days to arrive in Helena because the latest explosion there occurred five days prior to the time of the precipitation of this

TABLE 1—Fission Product Samples Collected at Helena, 1951

Sample Designation	Precipitation Type	Date	Time (Avg. Local)	Volume of Rain or Melt (ml)	Sample Type	Initial Activity Above Background (cpm)	Ratio to Background	Initial Activity per ml (cpm)	Approximate Initial "instantaneous half-life" (days)
A	Snow	2/11	1700	1,180	Cotton filter	95*	1.6	80.4×10^{-3}	5
B	Rain	10/6	1950	6,800	Evaporation residue	387	10.8	56.9×10^{-3}	6
C	Rain	10/14	2355	7,000	Evaporation residue	53	1.5	7.6×10^{-3}	>8
D	Snow	10/16	2000	4,450	Evaporation residue	27	0.76	6.1×10^{-3}	≅14
E	Rain	10/23	2000	10,000	Evaporated filtrate (cotton filter)	1,340*	39	134×10^{-3}	3
F	Snow	10/29	1030	5,980	Evaporation residue	1,800	50	301×10^{-3}	6
G	Snow	10/31	0400	75,000	Evaporation residue	342	9.7	4.56×10^{-3}	28
H	Snow	11/15	0400	23,400	Evaporation residue	130	3.7	5.55×10^{-3}	13

* This is not the activity of the total precipitation sample because the filters and filtrate share the total activity.

sample. This appears to be an unusually long travel time, particularly if any of the earlier explosions were responsible. According to qualified meteorologists (*5*) it is probable that the February 1 test was the source of the material of sample *A*, which moved south from Nevada, then west into the Pacific and back toward the northern United States. There is, however, a slight possibility that it traveled at low altitudes and low speeds directly from the test site toward Montana. There is also the possibility that the January 28th test produced material which might have circled the globe and then reached Helena after a travel time of 14 days. It is not known whether this could constitute tentative confirmation of the existence of the so-called jet stream, but large-scale tracer experiments of this nature might well be undertaken at the times of known nuclear tests.

It is of interest to note that the precipitation of samples *B* and *C* occurred 8 days apart and that of samples *B* and *D* 10 days apart, and that these were the samples which apparently originated in a foreign country. Columns 9 and 10, Table 1, show that the first of the three samples to arrive here is stronger and younger than the others, which suggests that they all originated in the same Russian explosion prior to October 3. If it is true that only one explosion provided the fission products of these three samples, then some meteorological explanation is needed, e.g. the "fission cloud" must have been either very large and/or was moving very slowly over Helena, was moving fast enough to encircle the earth between the time of the first and the latter two precipitations, or broke up into "clouds" traveling different routes, etc.

Comparing the shapes of those Fig. 2 curves of longest duration, one sees that *B* and *C* run more parallel to each other than to any of the others. (The rise in curve *C* beginning about seven days after the initial point is believed to be due to drying and cracking of the sample material.) The samples of Table 1, from *E* on, may or may not have originated in this country; if they did originate in this country, we thus see a different decay characteristic for the "foreign brand" explosion. The presence of significant amounts of longer-lived isotopes in samples *B* and *C* is apparent by their lesser decay rate compared to the other samples at equivalent times after several months. This suggests a possibility that the source of these foreign fission products might have been a pile (accident?) rather than a nuclear bomb.

Samples *B* and *C* would be expected to be "uncontaminated" by other explosions if they originated in the one 1951 Russian explosion prior to October 3. In interpreting the shapes of the Fig. 2 curves, the presence of mixtures of different ages from more than one explosion should be kept in mind, although this would seem to require that the later curves slope less.

Dating a Nuclear Explosion

The meteorological tracer problems suggested previously would be aided if one could know the date of the source explosion in each case, which would also be helpful in deciding between likely locations of the source explosion. An examination of the characteristics of mixed fission products suggests several methods of doing this.

A fission-product mixture from a nuclear explosion decays (*6*) by the approximate relation

$$A = A_1 t^{-1.2} \qquad (1)$$

where A is the activity at time t and A_1 is the activity at unit time after fission, in whatever time unit is used for t. Thus if a sample of such fission products is measured at two times t_a and t_b after fission, under identical geometrical conditions, and has activities A_a and A_b respectively

$$A_a = A_1 t_a^{-1.2} \qquad (2)$$

$$A_b = A_1 t_b^{-1.2} \qquad (3)$$

We know the calendar times of measurement of the sample but we do not

know t_a or t_b, either one of which would then tell us the calendar date of fission. We introduce an unknown constant p, defined as the time, in days and decimal fractions thereof, from the time of fission to time 0000 on the day of measuring A_a. We further define T_a as the time, in decimal fractions of a day, from 0000 on the day of the first measurement to the time of said measurement, and T_b as the time, in days and decimal fractions thereof, from 0000 on the day of measuring A_a to the time of measuring A_b. Then:

$$t_a = p + T_a \quad (4)$$

and

$$t_b = p + T_b \quad (5)$$

and Eqs. 2 and 3 become:

$$A_a = A_1(p + T_a)^{-1.2} \quad (6)$$

$$A_b = A_1(p + T_b)^{-1.2} \quad (7)$$

Dividing Eq. 6 by Eq. 7 and solving

$$p = (T_a - kT_b)/(k - 1) \quad (8)$$

where $k = (A_a/A_b)^{-1/1.2}$. The A's are in counts per unit time; absolute activities need not be known since the geometry cancels out.

With p calculated from Eq. 8, the time interval since fission is found using either Eq. 4 or 5 to give the time since fission as of T_a or T_b, respectively. Either one then provides the same calendar date for the time of fission.

The above considerations are presented to show how a fission product sample inherently contains information as to its birth date. These considerations form the theoretical basis for a graphical dating method using a gross decay curve calculated by Hunter and Ballou (7), which gives a more accurate relationship than that of Eq. 1. Ideally, one would compare the Hunter and Ballou curve as "standard," with the experimental sample decay curve and obtain the fission date by matching the two curves.

The "standard" decay curve is plotted on semi-log paper with abscissae labeled in days starting with zero. The abscissae of the experimental-sample curve are the actual calendar dates on which the activities were measured. With the two curves superimposed for the best fit, the number of days shown between the zero of the standard curve and the lowest calendar date of the sample curve is the number of days prior to this date that the fission occurred.

While this procedure should give good results for fission products under laboratory conditions, there are a number of complicating factors (in addition to those of multiple explosions) which arise with precipitation samples and which probably account for some of what happens when we try to date the origin of the samples of Fig. 2. For example, both Eq. 1 and the curves of reference (7) refer to fission products which have been, so to speak, "kept in a bottle" whereas fission products which have traveled hundreds or thousands of miles have been subjected to a certain amount of atmospheric chemical and physical action. Moreover, a nuclear explosion might produce, by neutron activation of bomb components and environment, some radioisotopes in addition to those of the fission process and ensuing decay chains. This activation depends on such things as bomb design, nature of construction materials, explosion location relative to ground, etc.

Also to be considered are the possible selective effects of filtering and/or boiling during sample preparation and the changing effect of self-absorption in the sample as the average energy of fission-product radiation increases with age. (If one were in a position to do so, these difficulties could be decreased by "calibrating" a known explosion, i.e., by collecting fission products after they had traveled away from an explosion of known type on a known date and using their measured decay as the standard for dating other explosions.

What happens when we try to fit the "standard" decay curve of Hunter and Ballou to the experimental curves of Fig. 2? Figure 3 shows that, considering all the unknown factors of the previous discussion, sample F fits the Hunter curve quite well over the 130 days that decay was measured. However, the other samples can be fitted only over parts of their decay curves, and so we cannot conclude that fission products decay with the same characteristics regardless of whether they have been "kept in a bottle" or subjected to the various influences previously discussed. However, applying the graphical dating procedure to sample F, the date of fission is found to be about 10 days prior to the time of precipitation here. If this date is even approximately correct, then the explosion probably occurred in Russia as it preceded the October–November Nevada tests and also falls in the interval announced by President Truman.

The best fit for sample $A1$ gives February 2 as the date of origin; this is consistent with reference (5). Definite conclusions are, of course, unreliable on this basis alone. When attempting so to date sample E, the Hunter curve can be made to fit either the early part of the sample curve (23-day interval) or the middle region (8-day interval), but not both at the same time. In one case the fission date coincides with the date of one of the Nevada tests and in the other with that test presumed from sample F to have occurred in Russia.

TABLE 2—Chronology of Nuclear Explosions in 1951

U. S. AEC: Nevada	U. S. AEC: Eniwetok
January 27	May (Operation Greenhouse; "several" explosions)
January 28	
February 1	
February 2	
February 6	
October 22	**Russia: Location not known**
October 28	Prior to October 3
October 30	Prior to October 22
November 1	
November 5	
November 19	

Note Added in Proof

On June 5, 1952, unusually high anomalous radioactivity was detected in this laboratory as a result of rain bringing down the fission products from the Nevada nuclear explosion of the same day. Readings as high as 1.5 mr/hr for gammas alone were obtained from the ground, people's shoes, and the city water supply.

Our first June 5th sample showed an initial activity of 1,280,000 cpm (extrapolated to same geometry as samples in Table 1)—a ratio of 36,000 to background and a count of 5,120 cpm/ml of rain. Calculation indicated that the activity was about 125 curies per square mile—over 1 kilocurie for Helena alone.

Samples from the same storm in other localities (courtesy R. A. Dightman) showed decay characteristics markedly affected by relative time and location of precipitation.

* * *

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VENTILATED CAVE is designed for use with highly active hard beta or gamma emitters. Operators use remote-control units

OPERATOR looks into cave through shielded window. With microphone, he directs workers in back who may be removing equipment

MOUND LAB—

Research in Secret

ONE OF THE MOST secret and least publicized sites of atomic energy work is the Mound Laboratory at Miamisburg, Ohio, operated by the Monsanto Chemical Company for the Atomic Energy Commission. Most of the highly classified process, research, and development work done there is related to production processes for fissionable material. Very little of the work, except some instrumentation, is unclassified.

The history of the project dates back to 1943 when Monsanto undertook a 6-month job for the Manhattan Engineer District. The present permanent site, near an Indian burial mound which gave the lab its name, was built in 1948.

The 241 technical people at the lab are divided into research, operations, biology, and engineering divisions. The total staff at Mound is 767.

Tracers are used at the lab for fundamental and applied research in inorganic chemistry. Very precise analytical work is done, with a whole group devoted to methods and testing. The research building is pressurized so that areas of low radioactivity are at higher pressure than those of high activity.

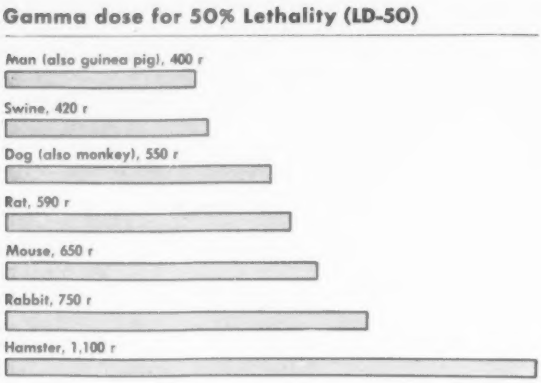
Major responsibility for waste-disposal research has been assigned to Mound. Priority goes to work on wastes from the plutonium-producing reactors at Hanford. The first analysis of the composition of these wastes was done at Mound.

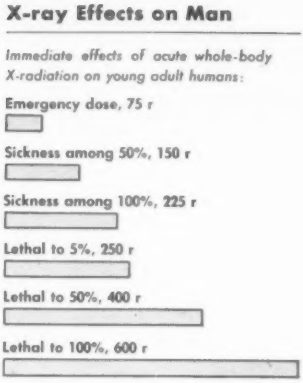
In addition to the Mound Laboratory, Monsanto also operates the Scioto Laboratory at Marion, Ohio, for AEC.

GERTRUDE, the coiled-spring device, is holding a small flask in her fingers over a sensitive balance. Cave is lighted with sodium-vapor lamps to eliminate diffraction through 2-ft windows that contain liquid with good stopping power for hard radiation.

QUARTZ-FIBER torsion microbalance, encased in massive shield, is accurate to 0.33×10^{-9} ounce. Operator sees a split image through the viewing periscope to improve depth perception (see cover photo). Fibers are 0.0005 in. in diameter

COUNTER in foreground has been adapted to handle as high as 22×10^{10} cpm. Walls, floor, and ceiling of counting room are lined with copper as a shield against stray electrical signals which might upset counters


Gamma dose for 50% Lethality (LD-50)
Man (also guinea pig), 400 r
Swine, 420 r
Dog (also monkey), 550 r
Rat, 590 r
Mouse, 650 r
Rabbit, 750 r
Hamster, 1,100 r


X-ray Effects on Man
Immediate effects of acute whole-body X-radiation on young adult humans:
Emergency dose, 75 r
Sickness among 50%, 150 r
Sickness among 100%, 225 r
Lethal to 5%, 250 r
Lethal to 50%, 400 r
Lethal to 100%, 600 r

Radiation Tolerances

Official recognition that the use of radiation involves health hazards came in 1921 when the British Committee on Radiation Protection suggested a "maximum tolerance dose." Now, three decades later, we are only beginning to get a picture of radiation's long-term effects

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QUITE OFTEN discussions of radiation effects are likely to distort the possible genetic hazards of radiation, that is, the body of data which show that certain radiation-induced changes appear in the genes that control heredity in future generations.

One such distortion, due probably to unfortunate condensation of an earlier, more extended statement, occurs on page 24 of the recently published "Handbook of Atomic Weapons for Medical Officers" (*1*). There it is stated that: "Little is known of the actual effects to be expected in man, but it is estimated that about 600 r would be required to produce significant mutation rate changes, and the fact of survival of an individual indicates a probable absorption of less than 450 r." Since well under 100 roentgens delivered to the germ cells of a considerable number of men or women might result in an easily recognizable increase in the number of malformed offspring in the next and subsequent generations, it is clear that the quoted statement is incorrect.

It is to aid in the recognition of the potentially important genetic hazards that this paper has been compiled.

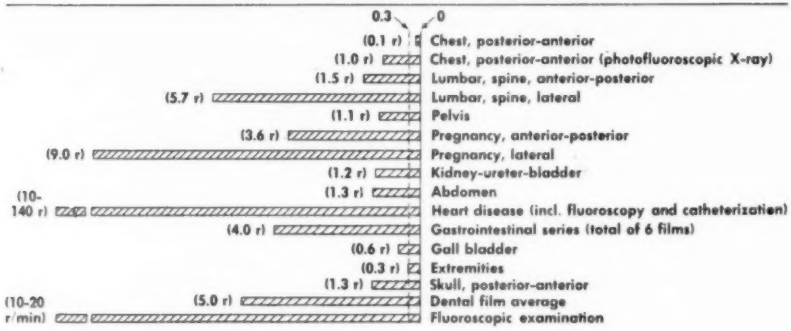
* Currently Assistant Chief, Biology Branch, Division of Biology and Medicine, U. S. Atomic Energy Commission, Washington, D. C.

Exposure Levels

In connection with the use of radiation for diagnostic examinations, sterilization, therapy, and general radiation-laboratory work, various data have been compiled on permissible exposure levels and doses; they are reviewed here to shed light on the long-term effects of radiation to be discussed later.

LD-50 for representative mammals. Permissible limits of gamma or X-radiation for men and animals are determined in terms of the LD-50, which is the acute whole-body dosage (lethal dose) that may be expected to result in the death of 50% of the animals exposed. The time interval usually

Exposures from Common X-ray Examinations



(Recommended maximum permissible dose = 0.3 r/week for occupationally exposed workers)

and Genetic Effects

specified is 30 days. Both the age and the strain influence the response to radiation exposure. Exhausting exercise following irradiation has also been shown to increase mortality in rats (*2*). The LD-50 figures for gamma radiation in the first graph are the current averages for young adult animals (*3*).

The relative effectiveness of other forms of ionizing radiation is indicated from data by Evans and Leinfelder (*4*). They found that for acute whole-body radiation of their strain of mice the LD-50 for X-rays was 500 r; for neutrons it was 100 n units. (One n produces approximately the same number of ionizations as 2.5 r.)

Permissible whole-body irradiation for humans. On the basis of the LD-50 figures given in the first graph together with observations on a small number of accidental exposures of laboratory workers, the expected immediate results from acute whole-body X-irradiation of young adult humans are indicated in the second graph.

In general, it is considered that 25 r cortical dosage of irradiation at any one time is the maximum man may receive without obvious illness (*5*). An exposure to 50 r may be expected to cause a reduction in lymphocytes only, while 100 r would result in nausea, vomiting, and fatigue in a large number of humans. At 200 r there would be a depression of all blood elements and definitely reduced vitality, but most of the cases would recover. One human accidentally exposed to over 350 r acute whole-body radiation, according to the best estimates, recovered completely after illness and temporary sterility.

Fractionated or daily doses and permissible limits of irradiation for humans. If we neglect the genetic effects, experience shows that the accumulation of small daily doses of whole-body radiation causes less obvious injury than a single acute dose.

Lorenz (*6*) was not able to show decrease in life expectancy in mice from as little as 0.1 r/day repeated through life, but there was a progressive decrease with 1.0 r, 4.4 r, and 8.8 r/day. Boche (*7*), however, shows results which are cumulative or nearly so. The best available evidence for small animals is that of Lorenz *et al.* (*8*) who showed that life expectancy for control mice was 716 days, while for animals exposed to acute whole-body radiation of 400 r at birth it was 401 days. For animals exposed to 4.4 r/day continued to death of the animal, the mean life expectancy was 552 days; after 8.8 r/day, it was 436 days.

There is reason to believe that chronic whole-body radiation in still smaller increments results in progressively decreasing mortality. Boche (*9*) indicates reduction in the number of spermatozoa in the dog from as little as 0.5 r per day. It is still possible, however, that recovery occurs from extremely small doses at daily intervals without permanent effects, and this assumption has been the basis for the determination of permissible levels of acute or chronic irradiation.

If 0.3 r/week, the dose recommended by the International Commission on Radiological Protection (*10*) as the permissible whole-body radiation limit should be received every week, it would add up to 15.6 r/year and 156 r in ten years. No such totals have been accumulated by AEC workers because exposures are carefully monitored; however, it is possible that, outside the United States, there are unmonitored plants or mines where workers are exposed to larger daily doses.

Exposures from common diagnostic examinations. The third graph above

DATA for Evaluating X-radiation Hazards in Animals and Man

	Drosophila	*Mouse*	*Man*
Direct effects on the Individual:			
1. LD-50, single dose killing 50%	30,000 r	650 r	400 r
2. "Permissible"* daily dose	5 r	0.1 r	0.1 r
3. Sterilizing dose to male gonads	5,000 r	500 r	500 r
4. Abnormal development, single dose to embryo	1,000 r	100 r	...
5. Sickness among 50%, single dose	...	...	150 r
6. Lethal to 100%, single dose	80,000 r	800 r	600 r
Genetic effects of accumulated doses to the gonads:			
7. Years per generation	0.1	1.0	30
8. Approximate number of genes	4×10^3	2×10^4	2×10^4
Natural or spontaneous rates			
9. Lethal mutations per gene per spermatozoon	10^{-6}	...	...
10. Mutations per gene per generation	...	8×10^{-6}	2×10^{-5}
11. Average 9 or 10 per germ cell per generation	0.004	0.16	0.4
Radiation-induced rates			
12. Lethal mutations per roentgen per gene	3×10^{-5}	...	...
13. Mutations per roentgen per gene	...	2.5×10^{-7}	...
14. Average 12 or 13 per roentgen per germ cell	1.2×10^{-4}	5×10^{-3}	(5×10^{-4})*
15. Per cent spontaneous mutations caused by natural radiation at 0.1 r per year	0.01%	0.3%	(3.7%)*
16. Number roentgens required to double spontaneous mutation rate	33 r	32 r	(80 r)*

* Figures were obtained by substituting mouse value of No. 13 in the man column.

summarizes the average exposures (approximate dose totals) from some diagnostic examinations in common use by radiologists (*11, 12*).

In certain diagnostic or therapeutic radiation exposures, substantial portions of the body may receive very much higher total exposures than shown by the graph. Sonnenblick *et al.* (*13*) found that certain fluoroscopes developed 70 r/min at the panel; for others the dosage developed was double that or higher.

While different organs and tissues show marked differences in radiation resistance, still the very widespread use of radiation in diagnosis and therapy may involve potential hazards to whole populations which could be far more serious in the long run than exposure of a small fraction to radiation effects from atomic explosions.

It is probable that every individual should carry a record of X-ray exposures from which his physician could always determine the total dosage he has received. An alternative would be a personal film badge.

In general, exposures of parts of the body are injurious in proportion to the fraction of the body exposed or perhaps the portion of the blood-forming organs radiated. Jacobson (*14*) has shown evidence that if the spleen is shielded from radiation, the body is protected from injury out of all proportion to the size of the organ.

Sterilizing dosage levels. The sterilizing dosages of radiation for laboratory animals have not been worked out precisely. Kaven (*15*) found that mice which were irradiated *in utero* between the 14th and 17th days of gestation showed complete male sterility with a dose as low as 178 r. W. L. Russell (*16*) reports that 600 r of acute whole-body radiation of male mice produces temporary sterility following temporarily lowered fertility, and the same result is known to follow a much lower dosage. Boche (*7*) has shown that doses of 200 r cause permanent sterility in female mice and a long sterile period in males.

The sequence of events in man is well known from the studies of the pathologists (*18*). Doses of about 250 r to the human testis cause degeneration of the spermatogonia, but eventually regeneration occurs with the formation of apparently normal spermatozoa. For irreversible sterilization a dosage of 500–600 r at the organ is required. The ovary is affected at lower doses delivered to the organ. Temporary sterility and amenorrhoea are produced at 170 r, and total sterility at about 300–320 r (*19*).

Irradiation Effects on Embryos

Direct irradiation of embryos developing in pregnant female laboratory mammals has been tried by a number of investigators (*15, 20–24*). Wilson and Karr (*22*) opened pregnant female rats at the 10th day and directed a beam of X-rays to certain embryo implantation sites. With control embryos for comparison, they concluded that a dosage of 50 r or less failed to produce any visible changes, 50–100 r was mildly effective, 100–200 r severely effective, and 200–400 r was lethal to the embryos. The embryos were removed at 1 to 5 days, killed, and studied histologically.

For mice, L. B. Russell (*23, 25*) showed that 200 r of X-irradiation of pregnant female mice $1\frac{1}{2}$ to $4\frac{1}{2}$ days after fertilization radically increased early prenatal mortality, and 300 r at $9\frac{1}{2}$ days may increase prenatal mortality in late stages. She considers that the gestation period of 19–21 days may be divided into three phases: (1) cleavage and implantation, during which 200 r produces a large number of prenatal deaths, but survivors are normal, (2) organo-genesis, during which irradiation causes little prenatal death but a high incidence of abnormalities at birth, and (3) fetal growth, during which irradiation with 200 r causes little effect at birth either in death or abnormalities. Some abnormalities resemble and others are unlike known genetically determined variations.

Later L. B. Russell and W. L. Russell observed that prenatal irradiation with as low as 25 r in mice produces noticeable changes on the development of pre-sacral vertebrae (*24*).

Hicks (*21*) found that neuroblasts and developing nerve cells in rats are the cells most sensitive to destruction by ionizing radiation. After 70–100 r, there was injury to the most rapidly growing parts of the fetal brain, spinal

cord and retina. After 150–200 r, the surviving fetuses showed severe brain malformations.

It is obvious that these results in laboratory animals suggest that great care should be used in exposing pregnant women to radiation even for diagnostic purposes.

Direct Effects on Adult Mammals

Shortly after an acute whole-body dose of 200 r or more to adult humans, there would be a substantial incidence to temporary nausea, vomiting, weakness, and prostration (*5*). About the second week after exposure, provided the dose was not lethal, the delayed symptoms would appear such as low blood counts, diarrhea, hemorrhages, and infections. More remote effects are graying of hair, epilation, increased rate of aging, as well as possible decreased life expectancy. Other long delayed results may be cataracts (*26*), greater frequency of leukemia, and perhaps increased incidence of cancer. Chronic or fractional exposures to parts of the body may eventually result in the appearance of any of these delayed effects, as suggested by a study made on the incidence of leukemia in physicians (*27*).

Long-term Effect on Populations

Muller (*32*) has calculated that the human race is in such a precise balance with respect to heterozygous genes which produce defectives, that an increase of even 25% in over-all mutation rate would produce a progressive and inevitable decline of the human population over a long period.

Wallace (*30*) shows that this result is not inevitable in *Drosophila* flies following moderate continued radiation doses. Populations exposed to 5 r day or a lifetime total of about 300 r adapt to this dosage by selection of balanced heterozygous chromosomes so that they maintain themselves and even increase in numbers in spite of the increased load of lethal and other mutations. Thus by stringent selection resulting in the killing off of many less resistant lines during the earlier generations, a population of flies is preserved that exhibits the beneficial effects of heterosis, or hybrid vigor, similar to that shown by the now widely cultivated hybrid corn.

When Wallace grew populations in cages receiving a lifetime total dose of about 2,000 r, however, the population rapidly declined. Thus it appears that fly populations have a considerable margin of safety, or genetic resilience, under radiation exposure, but they do so at heavy cost in elimination of individuals by human standards.

Wright (*31*) had earlier suggested this expectation for human populations. His calculations indicate that there is a considerable leeway in the genetic equilibrium of the human population; to quote, "There is, however, a strong possibility that cumulative doses of the order of 300 r may have important effects on the offspring and descendants of those affected, and doses as small as 30 r may not be negligible. On the other hand there is little or no threat to the persistence of the population from this cause."

The sensitivity of humans to radiation is greater than that of most other animals, so it is possible that widespread exposure to radiation would seriously reduce the numbers in the generation exposed. Marked reduction in numbers in any area might nullify the operation of selection and, unlike the flies, the human population might continue to dwindle.

However, the human population has survived many catastrophies in the past. It is unlikely that its survival would be seriously threatened by widespread radiation exposure from either diagnostic procedures or from atomic weapons.

Genetic Hazards of Radiation

It has been known since the critical studies of Muller in 1927 (*29*) that radiation induces inherited changes or mutations in animals. In contrast to the indications noted in earlier sections that small irradiation doses are not additive in their effects, the genetic studies indicate a linear-dosage/mutation-frequency relation and strongly suggest that fractional irradiation doses are cumulative in their mutagenic effects. The linear relation between X-ray and mutation frequency is most clearly indicated in the *Drosophila* data of Oliver (*33*) and Spencer and Stern (*34*). A similar relation is suggested by Muller (*29*) for neutron irradiation. For mammals, Charles (*35*) has provided evidence of the relation using mice.

Both the fly and the mouse tests indicate that approximately the same mutagenic effects are produced whether the exposure is a single one or an accumulation of small doses. Predictions of the mutagenic effects of various types of radiation on the genes of humans and other mammals have so far been based largely on *Drosophila* data. Here the results of Valencia and Muller (*28*), based on studies of lethal mutations, indicate a spontaneous lethal mutation rate of 10^{-6} per gene or (assuming 4,000 genes in the fly) 0.004 lethal mutations per spermatozoon. Wright (*31*) summarized these results and tabulated estimates of possible rates for Drosophila and man. More recently Muller (*29*) has revised all *Drosophila* estimates upward; this does not affect the over-all conclusions.

The estimates of human spontaneous mutation by Neel (*36*) based on certain rather rare genetically determined human diseases are about 2×10^{-5} per gene, or (assuming 20,000 human genes) 0.4 mutations per germ cell. This figure means that nearly every man or woman formed by the union of two germ cells carries one new mutation. Wright believes that this estimate is too high. He considers that in man, with small families, long-term selection must have resulted in a markedly reduced mutation rate from the figure indicated. As a more realistic estimate, he suggests 10^{-7} spontaneous mutations per gene or a total of 0.004 mutations per gamete, which is smaller than the number of new lethal mutations expected in *Drosophila*.

The natural background radiation, estimated to be at least 0.1 r per year (*37*) could account for a small part of the spontaneous mutations, but for man, in the extreme case, for not more than 4%. The *Drosophila* data indicate an increase in lethal mutations of 3×10^{-8} per roentgen per gene, or an increase per roentgen per spermatozoon of 1.2×10^{-4}. Thus the spontaneous rate of mutation based on lethals would be doubled by an exposure of spermatozoa to 33 r.

The extensive genetic studies on mice by W. L. Russell (*16, 17, 38*) are now giving data for mammals which allow more critical comparisons with the *Drosophila* data, and, by substitution, more realistic estimates of the mutagenic effects of irradiation in man. His breeding method allows a more exact determination of the mutation

JAPANESE STUDIES . . .

will be discussed in NUCLEONICS next month in an important progress report on the "Delayed Radiation Effects at Hiroshima and Nagasaki," by John C. Bugher, director of the AEC's Division of Biology and Medicine.

rate per gene, by recording the mutations found among the offspring of wild-type male mice mated to females heterozygous for seven easily recognized recessive genes. The mutants for these seven genes only are scored. The males are exposed to one dose of 600 r of 250-kv X-rays as young adults, and then after the temporary sterile period mated successively to unexposed females for as long as the males will breed. More than 38,000 control offspring from unexposed males and 48,000 offspring from irradiated males are reported.

One of the most obvious classes of mutations already noted by Charles and earlier geneticists, has been found by Russell (*17*) to be semi-sterility in the first-generation offspring of radiated parents. These have been shown to be due to chromosomal irregularities among the earliest functional spermatozoa which become available after the temporary sterile period of the radiated male parent. It is difficult to make precise estimates of their numbers, since they show a wide range of effectiveness. They apparently do not appear if mating is postponed for a certain period after radiation.

Russell has found 2 recessive mutations among the controls and 53 such mutants among offspring of the males exposed. The spontaneous mutations for these seven tested genes averages 8×10^{-6} per gene per generation. Assuming 20,000 genes, all of which mutate at the same rate, this gives 0.16 mutations per gamete, or an average of one spontaneous mutation for every three individuals, since each one represents the union of two gametes. The exposed animals give 2.5×10^{-7} mutations per gene per roentgen, or one additional mutation for every 100 gametes for each roentgen of radiation. If this rate holds for all genes, it means that every individual, one of whose parents has been exposed to 100 r, will carry a new mutation. These mutations are induced in the early testis cells (spermatogonia) of the mouse, since the radiated male is not mated until after the sterile period (*39*). Using these figures from Russell's studies, we can calculate that the dosage required to double the spontaneous mutation rate (or 100% increase) in mice is about 32 r, or about the same as calculated for lethals in *Drosophila*.

Neel's data (*36*) suggest that the human spontaneous rate for genes of all sorts is higher than either the *Drosophila* lethal rate or the mouse rate. If we use this estimate for the human spontaneous mutation rate and substitute Russell's figure from the mouse for the increase per roentgen per gene, we have a reasonable basis for the estimate that the human mutation rate will be doubled by an exposure to 80 r at a maximum. Since the human spontaneous mutation rate appears to be higher than either *Drosophila* or the mouse, it is possible that the increase due to radiation (rate per roentgen per gene) for men may also be higher. If this should be the case, the true value for doubling the human spontaneous rate by radiation may be closer to 30 r as for the other animals.

All these data are summarized in the table on page 18. The figure found for radiation dose required to double the spontaneous or natural rate of mutation has no inherent importance in itself except as it indicates the order of magnitude of the genetic effect of radiation. It suggests that the offspring of a man or woman whose germ cells receive a single or an accumulated dose of 80 r of radiation (or possibly as little as 30 r) may be expected to show an 100% increase in mutations over the number which will appear anyway. The hazard of even a slight increase in the numbers of deficient or malformed offspring, which is what an elevation in mutation numbers would entail, constitutes a problem worthy of serious consideration for every individual subjected to radiation exposure of the germ cells.

We cannot contemplate with equanimity an increase in deficient individuals or in the "genetic death" of the unborn.

Thus it is hoped that the foregoing facts and figures will indicate that radiation hazards cannot be neglected for human beings, even though they are not immediately apparent to the individual receiving the exposure.

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How To Get Samples Dated

Determination of the age of samples by the radiocarbon dating method has proved to be quite useful. NUCLEONICS lists here the requirements of four laboratories equipped to perform dating services

A NUMBER OF laboratories in this country are devoted to the use and development of the radiocarbon dating method developed by W. F. Libby.

To assemble in one place the requirements of four of these laboratories, NUCLEONICS asked them about their policies. Their answers follow.

University of Chicago

Organic materials such as wood, charcoal, peat, charred flesh, hair, and in exceptional cases antler and soil, containing 1 ounce of carbon, is the preferred type of sample. Shell can be used if in extremely well preserved condition. At least 6 ounces are required for a single measurement.

The samples are selected and assigned priorities on the basis of the advice of competent archeologists and geologists, such as Dr. Frederick Johnson of the Peabody Foundation for Archeology, Andover, Massachusetts, and Dr. Richard Foster Flint of Yale University.

Before samples are shipped the donor should correspond with the Chicago laboratory and if possible present evidence of sponsorship by a recognized archeologist or geologist.

Only a limited number of samples can be accepted and samples bearing on the validity of the method will be given preference.—*W. F. Libby, Institute for Nuclear Studies, University of Chicago, Chicago, Ill.*

Columbia University

The normal sample measured contains 8 gm of carbon. The separation and purification of the carbon is about 85% efficient so that 80–100 gm of calcium carbonate (shell or lime ooze), about 100–120 gm of dry wood, 20–30 gm of charcoal and several hundred grams of peat are required. Samples as small as 0.5 gm of carbon have been measured but much greater effort is required and less precision obtained.

Samples are screened by a committee of competent men in geology, archeology and geochemistry.

While a rather large quantity of samples can be handled, the high cost per analysis generally necessitates a contribution on the part of the sample sender toward the expense.

If a sample is of considerable scientific interest it can generally be dated in a few months. Present equipment permits dating to about 30,000 years. —*J. Laurence Kulp, Lamont Geological Observatory, Columbia University, Torrey Cliff, Palisades, N. Y.*

Yale University

No material is accepted for dating unless its provenience is certainly known; both geographic and stratigraphic information must be accurate and full.

Preference is given to samples whose dates are of more than local significance; the dates must be useful in illuminating wide fields of knowledge.

The guiding principle in selecting materials, at least for the next few months, is methodologic; not only are more modern assays needed, but in dating samples whose absolute age is unknown, preference is to be given to samples whose dates will throw light on the reliability of dates so obtained. In some cases the methodologic interest of old samples consists in the nature of the material or the circumstances of its preservation; in other cases, however, it consists in the ease with which a closely spaced series of stratigraphically dated samples can be obtained.

In general the Advisory Board is competent to decide on the order in which samples are processed. Preference will naturally be given to projects on which some Yale Faculty member can give an informed opinion. In all cases, however, and especially when research projects are suggested by others, the Advisory Board must be assured that a competent stratigrapher (geologist or archeologist) or historian will be prepared to vouch for the importance of the dates and to discuss their significance and validity.

Specimens should not be shipped until they are requested. Specimens should be dry when shipped; oven drying is preferred, and samples should be sealed from contact with air as soon as they are dry.

Aluminum foil is admirable for wrapping, but metal cans are satisfactory, and paper is acceptable provided it is not shredded. Excelsior and cotton should be avoided. Samples are ordinarily sealed in polyethylene (frozen-food) bags when received.

Parcel post, domestic and international, is ordinarily satisfactory. Specimens from abroad should not be dutiable; they should be marked "scientific specimens, of no commercial value." Shipment should be prepaid. —*Edward S. Deevey, Jr., Geochronometric Laboratory, Yale University, New Haven, Conn.*

University of Michigan

Specimens should be submitted to Dr. James B. Griffin, University Museums Building, who is chairman of a curatorial committee which passes on the materials and their scientific significance for the radiocarbon laboratory. Normally a charge of $100.00 a specimen is made to help defray the expense of the measurement.

The general requirements as to type and amount of material are the same as those outlined by Dr. Libby. Where possible a greater amount of material than the stated minimum should be provided.—*H. R. Crane, Harrison M. Randall Laboratory of Physics, University of Michigan, Ann Arbor, Mich.*

—END

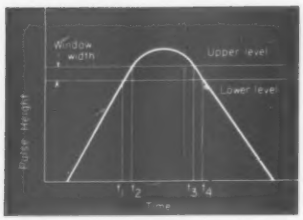

FIG. 12. Triggering action in a single-channel differential discriminator

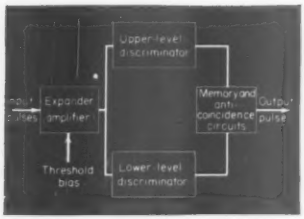

FIG. 13. Single-channel pulse-height analyzer with expander amplifier

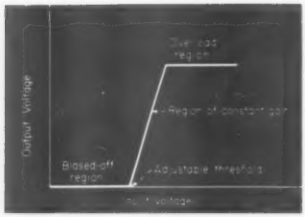

FIG. 14. Gain characteristic of idea expander amplifier

Pulse-Amplitude Analysis in Nuclear Research

PART II

SINGLE-CHANNEL DIFFERENTIAL ANALYZERS

In this article, circuits for a simple sweep-type, a moderate-precision, and a precision analyzer are treated in detail. Operating principles and design requirements are discussed

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A SINGLE-CHANNEL differential pulse-height analyzer is a device which generates an output signal if and only if an input pulse having an amplitude within a specified window is received.

Last month in Part I it was explained why a pulse-amplitude distribution curve obtained from data taken with a differential analyzer is subject to a smaller statistical uncertainty than one obtained by differentiating an integral-bias plot from a single discriminator.

A single-channel analyzer must determine two items of information: first, whether or not the pulse has crossed the lower boundary of the amplitude window, and, second, whether or not the pulse has crossed the upper boundary. In most analyzer designs, it is common for a lower-level crossing to generate an output signal which is suppressed if the upper level is also crossed. The signals indicating a lower- or upper-level crossing are usually obtained from two simple voltage discriminators.

A problem arising from the time relationships between the signals produced by the two voltage discriminators is illustrated in Fig. 12.* For an input signal whose amplitude exceeds the upper level, the signal from crossing of the upper level appears later and terminates earlier than that from crossing of the lower level. Hence, during time intervals t_1–t_2 and t_3–t_4, an output pulse might be gen-

* Figures 1–11 appeared in Part I of this article (NU, July '52, p. 20).

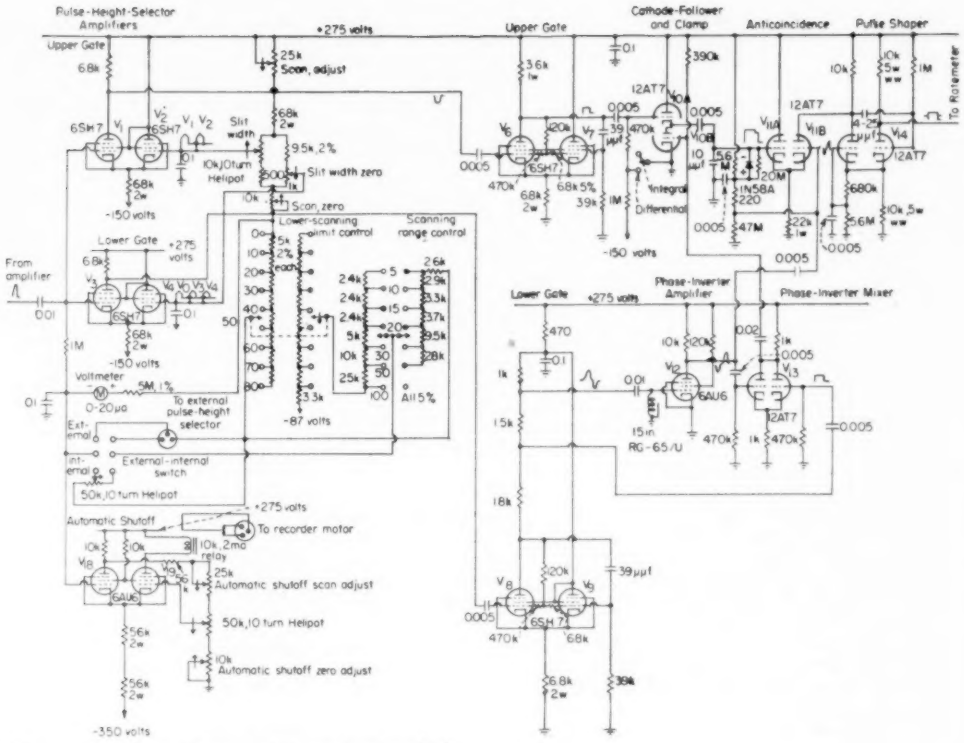

FIG. 15. Sweep-type differential and integral analyzer (19)

erated falsely. This difficulty can be overcome by storing the information concerning both the upper- and lower-level crossing until after the termination of the input pulse. This memory may consist of a charge upon a capacitor, the transition between two stable states of a trigger circuit, or a signal in a delay line. At a later instant, the lower-crossing signal can be transmitted as an output pulse only if a test shows that no upper-level crossing has occurred. Such circuits, by which an upper-level crossing suppresses the appearance of an output signal, are called anticoincidence or inhibiting circuits.

An early and crude anticoincidence technique which takes no cognizance of the time-relationship problem consists of connecting the outputs of two discriminators to the opposite ends of the primary winding of a coupling transformer (17). A proper output from the secondary occurs if only the lower-level discriminator is triggered. This technique can be used only where the input pulses are long and of proper shape.

A simple means for obtaining effectively a single-channel analyzer system without any need for anticoincidence circuits has been suggested by Frey (18). He simply observes the input-signal pulses with two discriminators (Schmitt circuits with preamplifiers) connected so that their biases, varied simultaneously by a helical potentiometer, differ by the constant potential obtained from a mercury cell—the window width. A scaling circuit is provided for each of the two discriminators. The number of input pulses having amplitudes within the window is the difference between the counts from the two scalers.

Although this arrangement is relatively simple, it requires one additional scaler and necessitates undesirable arithmetic in reducing the data. The resolving time and stability characteristics of the system are identically those of the two discriminators. Since the input pulses are common to both circuits, this technique reduces statistical errors in counting rate in the same manner as do conventional single-channel analyzers.

When input pulses are fed to two discriminators having a bias difference of perhaps a volt, the stability of discriminator threshold becomes of prime importance. A relative threshold drift of only 10 mv changes the window width 1%. One technique for alleviating this difficulty consists of preceding the two voltage-selector circuits with a common biased-off, expander, slit, or window amplifier as shown in block-diagram form in Fig. 13. The tops of pulses that exceed the expander threshold are

amplified by a constant gain factor, K (usually of the order of ten), and are supplied to the two discriminators.

The gain characteristic of an ideal expander amplifier is presented in Fig. 14. For a specified window width of s volts at the input, the discriminator biases now must be separated by Ks volts, so that the problem of window-width stability at the discriminators is made negligible. However, if the apparent window width at the input is to remain constant, the requirements on the expander are very severe.

Like a discriminator bias, not only must the expander threshold be adjustable over the desired spectrum range, but at any setting it must be as stable as possible. (Any drift in expander threshold will affect both discriminator levels about equally.) At low thresholds, many pulses will be sufficiently large to saturate the amplifier; it must, therefore, overload gracefully and not cause overshoots or other disturbances of the baseline.

By far most severe, however, are the requirements on gain stability, for the gain must remain as constant as possible, independent of threshold, time, pulse-frequency content (over a very wide frequency range), pulse size (except for overload pulses), and shape. The use of feedback circuits may be of assistance.

For example, consider an input pulse which rises 80 volts in 0.2 μsec. A perfect replica of an 8-volt portion of such a pulse from a gain-of-ten expander should rise 80 volts in approximately 0.02 μsec. To produce this rate of rise across an output capacitance of perhaps 40 $\mu\mu$f, the output tube must deliver a charging current of at least 160 ma. In Part I it was shown that the top of a $\frac{1}{2}$-μsec RC-shaped pulse which exceeds the expander threshold by 1% has a duration of only 0.028 μsec. The use of delay-line clipping, or "differentiation," is recommended to lengthen this duration and make the pulse top flatter.

No expander amplifier has been constructed which will satisfy all these requirements, although the performance of several designs described will meet the ideal specifications within an acceptable tolerance.

Sweep-Type Analyzer

A diagram for a sweep-type differential and integral analyzer of simple construction, reported by Fairstein (*19*)*, is shown in Fig. 15. Two discriminators, consisting of Schmitt circuits V_6-V_7 and V_8-V_9 with their preamplifiers, V_1-V_2 and V_3-V_4, are supplied with grid bias from a common helical potentiometer, the voltage range for which can be controlled by two multi-position switches. The window difference, which is established by returning the control grids of V_2 and V_4 to points of different potential, can be adjusted from zero to 10 volts with a second helical potentiometer labeled "slit width."

As explained in Part I, the preamplifiers preceding the Schmitt circuits perform the voltage-selection function, leaving to the Schmitt circuits the pulse-generating action. Advantages resulting from this combination are: (a) The first tube of the Schmitt circuit, turned off instead of on, can now operate initially with high transconductance. Thus, the second tube is turned on rapidly, thereby making possible a more abrupt and faster rise of output pulse and an improved response to extremely short input pulses. (b) The dynamic range of acceptable pulse amplitude may be extended because the minimum pulse size, a function of Schmitt-circuit hysteresis, is reduced by the gain factor of the preamplifier.

Tubes V_{10}-V_{14} perform the anticoincidence operation in the following manner: The lower-crossing pulse from the plate of V_8 is differentiated by a delay line consisting of 15 in. of RG-65/U coaxial cable. At the end of this pulse, a 0.15-μsec negative pip is produced, which, inverted in V_{12}, transmits an anticoincidence signal through difference amplifier V_{11} only if the upper level has not been crossed. The negative signal thus produced at the plate of V_{11B} generates in univibrator V_{14} a pulse of duration adjustable between 1 and 10 μsec.

In this instrument, pulses falling within the window are counted by a counting-rate meter (7) rather than by a scaler; the constant-amplitude pulses from trigger circuit V_{14} constitute the input pulses to the counting-rate circuit. Reference to the idealized waveforms in Fig. 16 will assist the reader in following the operations; dotted forms occur when the upper-level discriminator has been triggered.

If the upper level has been crossed, cathode follower V_{10A} deposits a positive charge on the 10-$\mu\mu$f memory capacitor connected between the cathode of V_{10A} and ground. This positive inhibiting signal at the grid of V_{11A} raises the common-cathode potential, thereby keeping V_{11B} cut off and suppressing the positive pulse from V_{12}. The charge stored on the 10-$\mu\mu$f memory capacitor is removed by clamp V_{10B} after the termination of the lower-level crossing. The lower-crossing signal is mixed with its derivative in dual-triode V_{13}; thus the clamp is held open during the lower-level crossing and for 0.15 μsec thereafter.

A helical potentiometer for manual control of window threshold is included in the analyzer. However, in the usual application of this instrument, the window is swept through the amplitude spectrum of the input pulses by means of an external motor-driven potentiometer, which, for convenience, may be coupled to the chart-driving mechanism of a recording meter. A plot of counting rate as a function of time—hence, as a function of bias—constitutes directly the pulse-amplitude spectrum. The sweep speed must be sufficiently slow to reduce adequately statistical variations in the recorded data.

If desired, an integral-bias spectrum can be plotted by disabling the upper-crossing memory circuit, thereby permitting every lower-crossing signal to generate an output pulse. A trigger circuit is provided which will shut off the sweep motor automatically when the threshold reaches a specified level, thereby making it possible to leave the instrument unattended during long runs.

This analyzer will accommodate positive input pulses having a maximum amplitude of 100 volts, a duration of 0.8–50 μsec, and a rise time of 0.1 μsec or greater. If delay-line differentiation in the amplifier driving the analyzer is used to flatten the tops of the input pulses, the instrument will operate with input pulses as narrow as 0.4 μsec.

Although the resolving time for the ratemeter alone is approximately 10 μsec, the resolving time at the input is essentially that of the anticoincidence gate circuits, about 2 μsec, because in practice only a small percentage of the input pulses are effective in actuating the ratemeter.

* A modified version of this unit is being manufactured by Tracerlab, Inc.

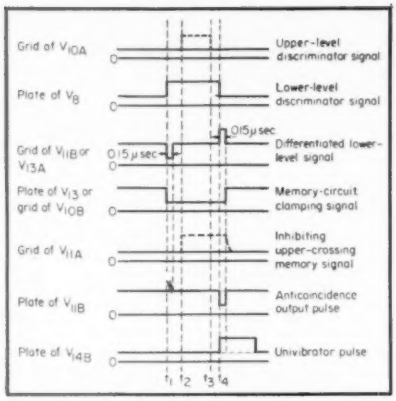

FIG. 16. Waveforms of analyzer in Fig. 15

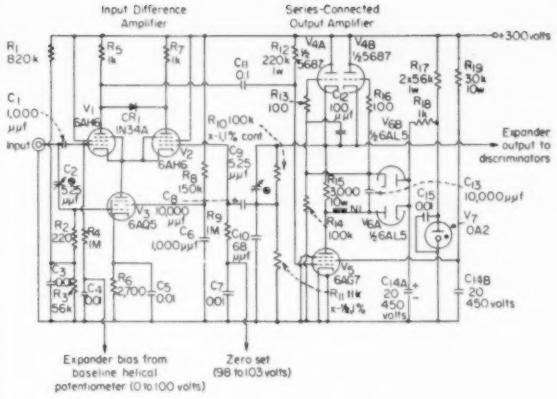
Input Difference Amplifier
Series-Connected Output Amplifier
+300 volts
Input
Expander output to discriminators
Expander bias from baseline helical potentiometer (0 to 100 volts)
Zero set (98 to 103 volts)

FIG. 17. Expander amplifier for single-channel analyzer (21)

Ratemeter sensitivity can be adjusted over a range of 250,000 to 1; a selection of ratemeter time constants from 0.1 sec to 2,000 sec is available.

Under laboratory conditions, if the analyzer is operated from a regulated power line and if the transconductances of the input discriminator tubes, V_1–V_4, are matched to within 10 μmhos, the drift in window width can be held within about 5 mv, or less than 1% of a 1-volt window.

Moderate-Precision Analyzer

A single-channel analyzer of a more complex nature, fundamently capable of high performance, has been designed by Higinbotham and Chase (*20, 21*).* This instrument, represented in block-diagram form by Fig. 13, contains an expander amplifier, followed by two discriminators and an anticoincidence circuit.

A detailed diagram of the expander is shown in Fig. 17. It consists of a biased difference amplifier V_1–V_3, driving a 2-tube, series-connected output stage (*22*). The second grid of the difference amplifier (which uses type 6AH6 tubes—a tube with high-gain × bandwidth) provides a convenient point for the introduction of a negative-feedback signal from the output. A constant-current tube, V_3, in the common-cathode return circuit permits application of the capacitive-feed-through-compensation technique described in Part I. Capacitor C_2 is adjusted until a large pulse of short rise time and amplitude insufficient to drive V_1 to conduction causes minimum disturbance of the potential at the plate of V_2.

The lower tube, V_5, of the series-connected output stage operates quiescently with approximately zero grid bias and a plate potential of about 80 volts. It views as a plate load a cathode-follower-and-resistor combination, V_4 and R_{15}, which exhibits a low quiescent voltage drop, but because the grid of V_4 is coupled through C_{13} to the bottom of the cathode resistance, appears to have a very high dynamic resistance. This dynamic resistance is $r_{p4} + (1 + \mu_4)R_{15}$, about 60,000 ohms, where r_{p4} is the plate resistance and μ_4 the amplification factor of V_4.

A frequency-compensated voltage divider (R_{10}, R_{11}, C_9, and C_{10}) returns 10% of the output voltage as a feedback signal to the difference amplifier. Since the loop gain is high, the over-all gain is essentially 10. Diode V_{6B} establishes the quiescent plate current and plate voltage for V_5 by fixing the quiescent potential at the grid of V_4, whereas V_{6A} limits the output signal amplitude to 70 volts by preventing the plate potential of V_5 from rising above 150 volts. (A second overload feature exists in the difference amplifier; too large an input pulse cuts off V_2, so that cathode degeneration drops the incremental gain to a negligible value.)

Capacitor C_{12} and the heater-cathode capacitance of V_{6B} are coupled to the plate of V_5, a high-impedance point, and are effective in establishing dynamic stability of the feedback loop and the bandwidth of the over-all amplifier.

Several cascaded breakaway circuits are included in this expander. These prevent the generation of an output signal until plate current in V_1 has increased to a predetermined value and is operating in a high-transconductance region; they also clip any negative overshoots which follow a large pulse. Diode CR_1 is the first breakaway element; quiescent plate current for V_2 flows in part through R_5 and in a forward direction through CR_1. The low-impedance grid circuit of V_5—which draws a 1.5-ma grid current during quiescence—constitutes the second element. As the plate current in V_1 increases due to an input pulse, current in CR_1 and in the control grid of V_5 is diminished. When both these currents have been reduced to zero, the plate of V_1 is freed and able to deliver an output signal. Diode V_{6B} constitutes the third breakaway element; it conducts quiescently a current of 1.5 ma. The plate potential of V_5 thus will not change until plate current in V_5 has decreased by this amount. Because of the high gain preceding this point, diode V_{6B} probably contributes most to the sharp break in leading edge of the output pulse.

Figure 18 is a detailed diagram of the level selectors and anticoincidence

* This unit is being manufactured by the Atomic Instrument Company.

circuits. A lower-level, or baseline, discriminator, V_{11}-V_{12}, and an upper-level, or window-width, discriminator, V_8-V_{10}, are both connected to the output of the expander amplifier. The window-width discriminator incorporates a constant-current cathode-return tube, so that capacitive-feedthrough compensation may be applied. No such provision is needed in the baseline discriminator, for unlike the grid of V_8, the grid of V_{11} is not subject to large, fast signal swings below threshold.

Positive pulses from the baseline and window-width discriminators, coupled through cathode followers V_{12B} and V_{12A}, via diodes V_{14A}, CR_4, and CR_5, each deposit a fixed charge on memory capacitors C_{30} and C_{31}, respectively. At the termination of a baseline pulse, capacitor C_{31} discharges through R_{57}, delivering a negative exponential to difference amplifier V_{13}. A negative output pulse is produced at the plate of V_{13A} only when no simultaneous inhibiting signal is received from C_{30}. Breakaway diode CR_6, connected between the plates of V_{13}, eliminates any small positive output pulses which might be generated when both discriminators are fired.

Diode V_{14A} allows the inhibiting signal, produced after an upper-level crossing by the discharge of C_{30} through R_{53}, to be delayed until the end of the lower crossing, when the negative step from V_{13A} is applied simultaneously to both grids of V_{13} via two paths: (a) V_{14B} and C_{30}, and (b) C_{31}. Isolating diode CR_3 prevents positive pulses which may appear across CR_4 during the charging of C_{30} from causing a false output signal.

A precaution is taken to make the window-width discriminator signal sufficiently long so that it will fully charge memory capacitor C_{30}. If the discriminator is triggered by a very short input pulse, a holding circuit, CR_2, C_{29}, R_{51}, and R_{50}, prevents the discriminator from returning until after a minimum delay (approximately 1 μsec) determined by the time constant associated with C_{29}. Capacitor C_{29} is connected from the output of cathode follower V_{12B}, via diode CR_2, to the cathodes of V_8 and V_{10}. No such feature has been provided for the baseline discriminator.

Threshold bias over a range of 0–100 volts for the upper-level discriminator is obtained from a helical potentiometer. The baseline discriminator has a hysteresis of approximately 3 volts; it is adjusted by R_{44} for a fixed threshold of about 5 volts, so that the tail of a signal pulse will not cause an excessively long discriminator signal. Hence, an input pulse must exceed the expander threshold by about ½ volt before triggering the baseline discriminator. Plate-supply potential for the entire analyzer is obtained from a highly regulated power supply.

The performance of this analyzer is limited mainly by the bandwidth of the expander amplifier. Although the drift, with time, in level and in window width at the discriminators is negligibly small, the effective window width at the expander input (measured with the baseline control) varies, for example, as much as 4%, when one observes with a 2½-volt window-width setting an adjustable-amplitude square pulse having a duration of 1 μsec (with rise and fall time constants of 0.2 μsec).

It has also been suggested that the potentially nonlinear characteristic of cathode follower V_2 in the feedback loop may cause an apparent change of window width. A difficulty arises in adjusting C_9 for proper transient response. Because of the large time constants in the feedback voltage divider, capacitor C_9 determines not only the leading edge response, but the gain for the body of a typical pulse as well. It must be adjusted for an expander-amplifier gain of 10.

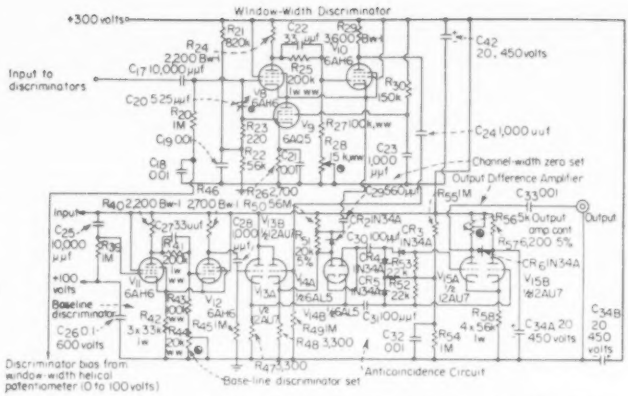

FIG. 18. Discriminators and anticoincidence circuit for single-channel analyzer (21)

Precision Analyzer

A single-channel analyzer of considerable precision has been developed by Francis (23). The design, which has evolved from several previous models (24), can also be represented by the block diagram of Fig. 13.

A diagram of the expander amplifier is shown in Fig. 19. It consists of a cathode-follower input stage, V_1, biased by means of a 50,000-ohm helical potentiometer to the desired threshold, followed by a 3-tube, gain-of-10 feedback amplifier, V_2–V_5.

A wide band is obtained through the use of the type 404A pentode, a tube having a gain-bandwidth product higher than that of any conventional receiving tube. The cathode-follower output stage, V_5, of the feedback amplifier supplies a portion of the input signal, amplified by a factor of ten, to the discriminators following.

A paraphase signal, useful for compensating against the effects of undesired capacitive coupling, is obtained from the plate of V_3 through the use of a 2,400-ohm plate-load resistance.

Cathode follower V_1 operates linearly and is direct-coupled to the control grid of V_2; a change in expander threshold merely shifts the d-c level of the output pulse from V_1. Pentode V_3 is cut off quiescently; a pulse which causes the cathode potential of V_1 to exceed sufficiently the cut-off bias for V_3 will generate a negative signal at the plate of V_3.

Two signal overload features are provided. The first consists of duo-

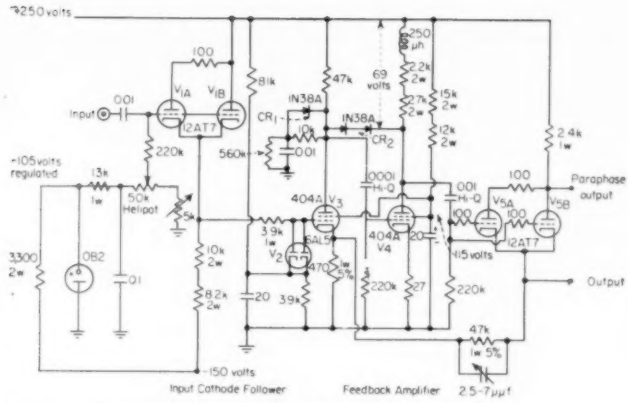

FIG. 19. Expander amplifier for precision single-channel analyzer (23)

diode V_2 which prohibits the control grid of V_3 from drawing grid current. A 3,900-ohm series resistor permits the cathode of V_1 to continue rising after V_2 conducts, thus preventing any flow of grid current in V_1 which would charge the input coupling capacitor. The second feature is a 1N38A crystal diode, CR_1, connected from the plate of V_3 to the junction of a by-passed voltage divider to prevent the potential of the plate from falling more than about 10 volts below its quiescent value. Because of the limited signal swing, the plate potential of V_3 will recover rapidly after a large signal.

An abrupt and fast rise of output pulse is insured through the use of an "amplified-diode" breakaway circuit. Two 1N38A crystal diodes, CR_2, connected in series between the plates of V_3 and V_4, prevent any signal output at either plate until V_3 draws a plate current of about 1½ ma. The diodes also clip any negative overshoots which follow a large pulse. For increments, these diodes are connected between grid and plate of V_4. As a result of the Miller effect, the impedance presented by these diodes between the plate of V_3 and ground appears to be diminished, thereby sharpening the apparent volt-ampere characteristics of the diodes (*13*).

For a more rapid response, and to increase the linear range of amplitude response of the expander, a compensating inductance has been inserted in the plate circuit of V_4. Parasitic-suppressing, 100-ohm resistors have been connected in series with several of the tube elements to reduce any likelihood of self-oscillation.

Figure 20 presents a detailed diagram of the discriminators and anticoincidence circuits. Lower-level discriminator, V_8-V_9, and upper-level discriminator, V_6-V_7, are capacitance-coupled, regenerative-clipper circuits. Type 404A pentodes with shunt compensation in the plate circuits of V_6 and V_8 provide rapid response. Threshold bias for the lower-level circuit is fixed; bias for the upper-level circuit is obtained from a 25,000-ohm helical potentiometer.

The paraphase signal from the expander amplifier, coupled through an adjustable trimmer capacitor to the cathode of V_6, compensates against capacitive feed-through via the grid-cathode capacitance in V_6. As before, no such compensation is needed in the baseline circuit.

The technique of anticoincidence is analogous to that used in the sweep-type analyzer described earlier. The positive signal generated at the plate of V_9 by the lower crossing is delay-line differentiated; the negative pip so produced at the end of this signal is coupled through crystal diodes CR_5 and CR_6 in the anticoincidence circuit to the grid of V_{12A}. After being inverted and strengthened in amplifier V_{12A} and cathode follower V_{12B}, this pip becomes the output signal.

An upper crossing inhibits the transmission of the pip in the following manner: A positive upper-crossing signal from the plate of V_7 charges, through diode CR_3, the grid-ground capacitance of V_{10}—the memory capacitance. This stored positive pulse lifts the cathode potential of crystal diode CR_5 via CR_4, thereby blocking the negative baseline pip from the grid of V_{12A}.

The memory capacitance is shunted by clamp V_{11}, a 6AS6 coincidence pentode which prevents any storage of memory signal except during the baseline crossing and for 0.1 μsec thereafter. The clamp is held open during the baseline crossing by the negative signal from the plate of V_8; it is held open for 0.1 μsec thereafter by the negative pip resulting from the differentiation of the positive baseline signal.

Performance of this analyzer is adequate for all but the most exacting applications. Because of its wide band, the expander amplifier can reproduce faithfully any portion of an *RC*-shaped pulse having a duration of approximately 1 μsec and a rise time as short as 0.2 μsec. Equally short delay-line-shaped pulses and longer *RC*-shaped pulses obviously do not tax the analyzer's capabilities. Its window width is expected to remain constant to within approximately 25 mv.

As in the sweep-type analyzer, these anticoincidence circuits are characterized by unusual speed. The analyzer is fully able to accept a new input pulse only ½ μsec after the termination of a previous pulse.

Other Types

Many other designs for single-channel analyzers exist. Elmore and Sands have described a wartime instrument (*7*) utilizing two Schmitt circuits with biases adjusted by a common control, but separated by a constant window difference. This instrument includes auxiliary timing circuits which permit an input pulse to be viewed only during the short interval when the pulse reaches its peak. False results due to pile-up of a pulse on the tail of one preceding are thereby essentially eliminated. The anticoincidence circuits are similar to those in the moderate-precision, single-channel analyzer described before. The stability of window width and level is of the order of 0.1 volt.

The work of Glenn (*25, 26*) and Watkins (*27*), who applied beam-deflection techniques to the multi-channel analysis problem, suggests the

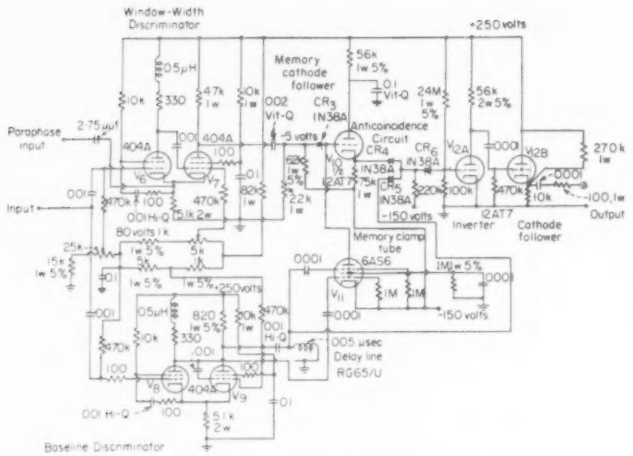

FIG. 20. Discriminators and anticoincidence circuit for precision analyzer (23)

use of a beam-deflection method for a single-channel analyzer in which the channel is defined on the face of a cathode-ray tube by a phototube and mask, or is specified by the geometry of one or more internal collecting electrodes in a specially constructed beam-deflection tube.

Of these two possibilities, the first is more versatile, but suffers loss of precision because of light scattering in the phosphor and glass. The second method does not permit easy adjustment of window width. Both methods depend on beam-deflection sensitivity —a function of accelerating potential.

Because of the finite width of an electron beam and the effects of secondary emission from the electrodes, the sharpness of discrimination of a beam-deflection tube is often inadequate, and additional discrimination following it is necessary.

Single-channel analyzers provide a method for determining pulse-height distributions which is satisfactory for most laboratory applications. Their use is time-consuming, however, in that the determination of each point in a distribution plot requires a separate counting interval sufficiently long to reduce adequately statistical counting errors (*28, 29*).

It must be remembered that data taken with a single-channel analyzer are meaningless if the shape of the distribution curve changes during the period of measurement or if the total counting rate is not constant (unless data taken are corrected for any such variations).

Where time is at a premium, possibly because of low counting rate, or because of variations in total counting rate, the use of a multichannel analyzer which acquires data in all channels simultaneously is preferable.

NEXT IN THIS SERIES . . .

will be articles on
Multichannel analyzers—I
Multichannel analyzers—II
in September and October, respectively.
The first in the series was on
Voltage discriminators
and appeared in the July issue

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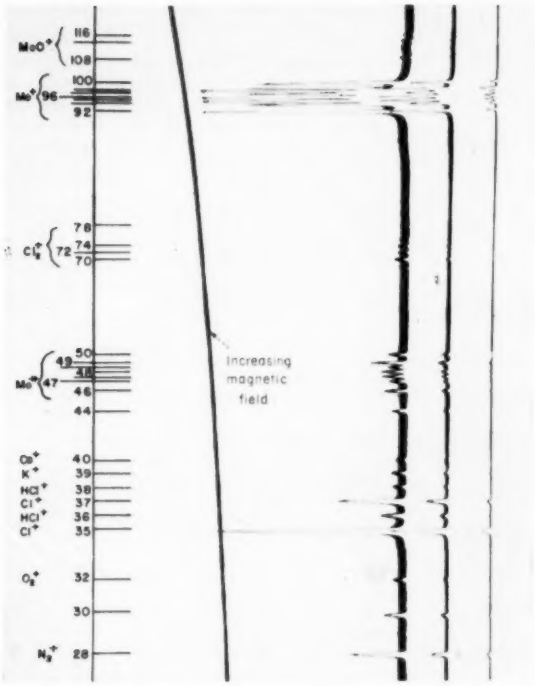

ION MASSES in beam as chlorine gas is passed over heated MoO_3 charge

Stable isotopes are enriched in Oak Ridge mass spectrographs called calutrons. A summary of the materials so far successfully processed is given on the following pages. It tells, in effect, the story behind AEC's large inventory of stable isotopes, four fifths of whose users are non-AEC labs

By C. P. KEIM
Y-12 Area, Oak Ridge National Laboratory
Oak Ridge, Tennessee

ALMOST FIFTY ELEMENTS of the periodic chart have been successfully processed in the calutrons (mass spectrographs) at Oak Ridge and their isotopes thereby enriched.* The initial problem in this isotope separation method, which is described here, is to select and obtain or prepare suitable starting materials that will produce a copious supply of positively charged ions under the operating conditions of the calutron when used for the enrichment of stable isotopes.

A charge bottle is used to hold the element or one of its compounds which

* C. P. Keim. The concentration of stable isotopes by the electromagnetic method, *Chem. Eng. News* **25**, 2624 (1947)
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Charge Materials, Temperature Range, and Collector

Isotopes	Best charge material	Source oven temp. range ° C	Collector material: Graphite not cooled	Collector material: Copper water-cooled	Remarks
Li-6,7	LiBr and Li metal	480–550		x	LiBr and Li metal mixture.
Be-9,(10)	$BeCl_2$	200–350	x		Be^9 charge material was irradiated in the pile resulting in mixture of Be^9 and Be^{10}.
B-10,11	BCl_3	220–385		x	BCl_3 is a gaseous compound at room temperature but heating was necessary to prevent forming certain B compounds.
C-12,13	CO_2			x	CO was slightly better but is toxic.
N-14,15	N_2		x		Commercial N_2; Mg shavings were placed in collector to form nitride.
O-16,17,18	O_2		x	x	Commercial O_2; Cu shavings were placed in carbon collector to form oxide.
Mg-24,25,26	Mg	480–600		x	Degreased and dried Mg turnings were best; $MgCl_2$ and MgI_2 gave fair results.
Si-28,29,30	$SiCl_4$			x	Gaseous $SiCl_4$.
S-32,33,34,36	CS_2			x	H_2S was tried; fine Cu turnings in the collector formed Cu_2S.
Cl-35,37	$CuCl_2$	250–415		x	Finely divided barium in collector formed barium chloride.
K-39,40,41	KI	590–630		x	K metal gave poor results except with stainless steel accelerating electrodes.
Ca-40,42,43,44, 46,48	Ca	625–990		x	Ca metal.
Ti-46,47,48,49, 50	$TiCl_4$		x		Gaseous $TiCl_4$. Ti metal gave poor results.
V-50,51	VF_3	225–800	x		VF_3 properties uncertain.
Cr-50,52,53,54	$CrCl_3$	445–850	x		$K_2Cr_2O_7$, Cr_2O_3 and CrO_2Cl_2 were also investigated.
Fe-54,56,57,58	$FeCl_2$	480–590	x	x	Cu pockets gave best retention. Carbon was used for Fe^{58} pocket to receive strongest isotope beam.
Ni-58,60,61,62, 64	$NiCl_2$	500–635	x		Prominent side bands of Fe and Cu were present.
Cu-63,65	CuCl	350–425	x		Ni sidebands were present.
Zn-64,66,67,68, 70	Zn	360–590		x	Zn metal was chosen over the halides because of more desirable vapor pressure characteristics.
Ga-69,71	GaI_3	120–180	x		
Ge-70,72,73,74, 76	$GeCl_4$		x		Gaseous charge.
Se-74,76,77,78, 80,82	SeO_2	150–250		x	Se metal was also tried but probably vaporizes as Se_8.
Br-79,81	$SrBr_2$	650–750		x	Cadmium strips were placed in collector to accomplish chemical combination of Br and Cd.
Rb-85,87	RbI	520–680		x	
Sr-84,86,87,88	Sr	535–685		x	Ion output from $SrBr_2$ charge material was not as high as the metal.
Zr-90,91,92,94, 96	$ZrCl_4$	150–340		x	Low ion outputs.

can be vaporized. Made of a metal with a high melting point like stainless steel and one not readily attacked chemically, this charge bottle is maintained at a regulated temperature in a calrod-heated oven and the vapor density carefully controlled.

If the charge material has sufficient vapor pressure at room temperature, it is piped into the ion source from outside the vacuum chamber. As the vapor passes through a chamber of graphite, it is ionized by a stream of electrons.

The positive ions produced are of various kinds depending on the initial charge material. For example, if the charge material is MoO_3, there are ions of MoO^+, Mo^+, Mo^{++}, O_2^+, etc.

For most effective separation of the isotopes of molybdenum, a maximum number of Mo^+ ions are needed. The picture on the preceding page shows some ion masses in the beam as a charge material of MoO_3 is used and chlorine gas is passed over the heated MoO_3. The positive ions formed are accelerated by an electrical field and travel across a strong magnetic field in circular paths of different radii.

Suitable collectors can be placed at the 180-degree position of ion travel to receive and retain various isotope ions. These isotope collectors must withstand ion-beam erosion, they must not contaminate the isotopes by introducing undesirable chemical or isotopic impurities, and they must be kept at a temperature which results in a low vapor pressure of the isotopes being collected so as to reduce the escape of collected isotopes. Graphite

Materials Used in Stable Isotope Separations

Isotopes	Best charge material	Source oven temp. range °C	Collector material: Graphite not cooled	Collector material: Copper water-cooled	Remarks
Mo-92,94,95,96, 97,98,100	$MoCl_5$	50–185	x		Chlorine was passed over heated MoO_3.
Ag-107,109	AgCl	500–690		x	Chlorine was passed over Ag metal in heated charge bottle; the bromide and the iodide were also tried.
Cd-106,108,110, 111,112,113, 114,116	$CdCl_2$	455–485		x	The metal and the halides were examined.
In-113,115	InI	175–255	x		InI_3 proved not as good as InI.
Sn-112,114,115, 116,117,118, 119,120,122, 124	$SnCl_2$	220–580	x		$SnCl_4$ gave fair results.
Sb-121,123	Sb_2O_3	355–470		x	Antimony metal was tried; stainless-steel water-cooled collectors were also used.
Te-120,122,123, 124,125,126, 128,130	TeO	425–900		x	$TeCl_4$ gave fair results
Ba-130,132,134, 135,136,137, 138	Ba	725–800	x		Ba metal.
La-138,139	$LaCl_3$	475–750	x		
Ce-136,138,140, 142	$CeCl_3$	515–775		x	
Nd-142,143, 144,145, 146,148,150	$NdCl_3$	500–690	x		
Sm-144,147, 148,149, 150,152,154	$SmCl_3$	540–800		x	Sm metal, Sm_2O_3, and Sm halides were tried.
Hf-174,176,177, 178,179,180	$HfCl_4$	110–170		x	
W-180,182,183, 184,186	WCl_6	75–125		x	Tungsten halides, the oxide and oxychloride were tried; also Cl_2 was passed over the metal.
Re-185,187	Re_2O_7	190–300	x		Re_2O_7 is extremely hygroscopic.
Hg-196,198, 199,200, 201,202,204	$HgCl_2$	50–110		x	Water-cooled silver collectors for amalgamation purposes were most successful.
Tl-203,205	TlI	335–370		x	Tl metal, the bromide, chloride and nitrate were investigated.
Pb-204,206,207, 208	$PbCl_2$	410–495		x	

is a common collector material if water cooling is not necessary to keep the temperature low. If water cooling is necessary, copper or stainless steel is often used.

In practically all calutron separations, the isotope is collected as the simple element, seldom in any compound form. The reason for this is that, regardless of the charge material, most of the molecules are stripped down in the electron bombardment to what amounts to the simplest singly charged elemental ion.

Occasionally it is advantageous to encourage a chemical combination between the isotope being collected and the collector material. The isotopes of mercury provide an illustration of this scheme. They were successfully enriched by reducing the vapor pressure of mercury at the collector by subzero cooling. By using silver as the collector material, a mercury-silver amalgamation was accomplished and retention of the mercury isotopes in the collector was greatly increased.

The most successful charge materials of many of the elements whose isotopes have been enriched in the calutron are summarized in the accompanying table, along with information on what collector materials were used to retain the separated ions and whether or not water cooling was necessary.

* * *

The assistance of L. O. Love and J. R. Walton, who supplied the operating data for this report, is greatly appreciated. The survey is based on work performed for the Atomic Energy Commission by Carbide and Carbon Chemicals Company, a division of Union Carbide and Carbon Corporation.

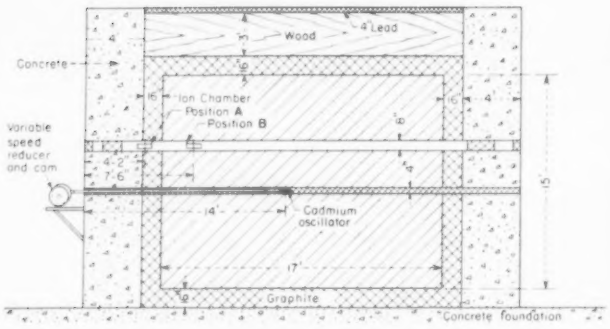

FIG. 1. Cross section of CP-2 reactor showing equipment location

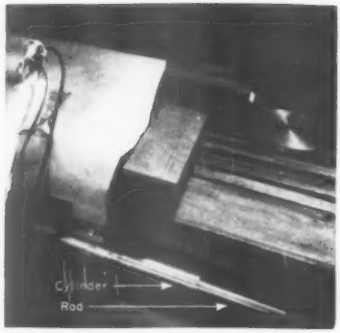

FIG. 2. Cd rod used to vary reactivity

Transfer Function of Argonne

The kinetic behavior of CP-2 has been determined for sinusoidal variations of reactivity. Variations of phase and amplitude of the neutron density have been both measured and calculated

THE GENERAL TREATMENT of the time-dependent response of a reactor to a local change in reactivity is quite complicated, and involves explicitly the geometry of the reactor (*1*).

If the reactivity change is distributed uniformly over the reactor volume, only the fundamental space mode of the reactor is involved (i.e., the initial space distribution of neutron flux is preserved), and the only reactor characteristics needed to describe the response are the neutron lifetime and the delayed-neutron characteristics. The same is true for a localized reactivity variation if the time rate of change is low enough, and if the response is measured at some distance from the location of the reactivity change. The latter conditions hold for many cases of practical interest, especially in the design of reactor control systems, where mechanical considerations put limitations on the speed with which reactivity changes can be produced.

For these cases, a particularly useful way of describing the kinetic behavior of a reactor is in terms of its response to small-amplitude sinusoidal variations of reactivity. Thus the application of a "driving function" is visualized in the form of a sinusoidal reactivity variation to the reactor, and the behavior of the reactor is described by the amplitude and phase relation of the resulting steady-state sinusoidal variation of power output or neutron flux level.

These phase and amplitude relations, when stated as functions of the driving frequency, will be designated here collectively as the reactor transfer function. The transfer function can be used in the usual way for the design of servo loops or regulating systems which include the reactor.

It should be emphasized that, for a given driving frequency, the input and output amplitudes are related linearly only if the amplitudes are small. In the design of control systems, whose function is to hold reactor power at a desired level, i.e., to suppress rapid reactivity changes of large amplitude, this limitation is not serious.

An experimental measurement of the transfer function of the CP-2 reactor at Argonne National Laboratory has been performed, and the measured function compared with that derived by calculation. The measurement was undertaken as an exploratory project, primarily for the purpose of developing techniques for use on other reactors.

The apparatus used was assembled from readily available components, and neither extreme accuracy nor refinement of design was attempted. Reasonable agreement with the calculated function was obtained.

Figure 1 is a side view of the reactor, showing the positions of the ionization chamber used to detect the neutrons, and the position of the oscillating rod used to vary the reactivity. Figure 2 shows the cadmium rod encased in a cadmium cylinder that is used to vary the reactivity, and Fig. 3 shows the drive mechanism for the oscillating rod, and the position indicator.

Reactor Kinetics Equations

The time dependent reactor equations (with the Fermi slowing down distribution) for thermal flux are (*2*)

$$(\lambda_t/3)\,\Delta nv - nv\Sigma_a + (nv\Sigma_a k_p + \lambda c)e^{r\lambda} = \partial n/\partial t \quad (1)$$

$$\partial c/\partial t = nv\Sigma_a k_d - \lambda c \quad (2)$$

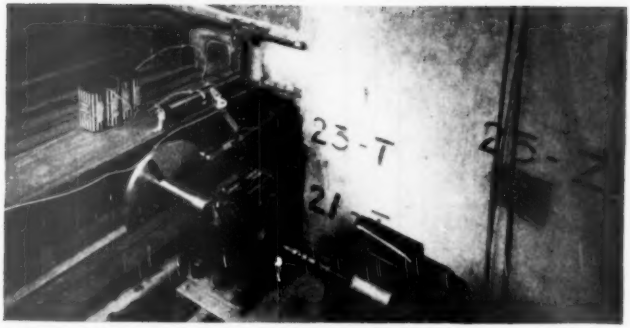

FIG. 3. Oscillator drive mechanism and position indicator

CP-2 Reactor

By J. M. HARRER, R. E. BOYAR, and DARWIN KRUCOFF

Argonne National Laboratory
Chicago, Illinois

where $k_\infty = k_p + k_d$, and k_p and k_d refer to the portions of k_∞ which produce prompt and delayed neutrons, respectively. It is here assumed, for the moment, that there is only one group of delayed neutrons (see Eqs. 8 and 9). If only the fundamental space mode is involved, $\Delta nv = Knv$, (K = constant), and with $T_0 = 1/v\Sigma_a$ the time dependent portion becomes

$$\lambda_i K n/3\Sigma_a T_0 - n/T_0 + (nk_p/T_0 + \lambda c)e^{\tau K} = dn/dt \quad (3)$$

$$L^2 = \lambda_i/3\Sigma_a \quad \text{and} \quad k_p = k_\infty(1-\beta)$$

$$(L^2K - 1)n/T_0 + nk_\infty(1-\beta)e^{\tau K}/T_0 + \lambda c e^{\tau K} = dn/dt \quad (4)$$

Rewritten, this is

$$\frac{k_\infty - (1 - L^2K)e^{-\tau K}}{k_\infty(T_0/k_\infty e^{\tau K})}\, n - \frac{\beta n}{T_0/k_\infty e^{\tau K}} + \lambda c e^{\tau K} = dn/dt \quad (5)$$

then with

$$l^* = T_0/k_\infty e^{\tau K}$$

and

$$\frac{k_\infty - (1 - L^2K)e^{\tau K}}{k_\infty} = \delta k$$

Eq. 5 becomes

$$dn/dt = \delta k n/l^* - \beta n/l^* + \lambda c e^{\tau K} \quad (6)$$

and Eq. 2 becomes

$$dc/dt = n\beta k_\infty/T_0 - \lambda c$$

or

$$e^{\tau K}\, dc/dt = \beta n/l^* - \lambda c e^{\tau K} \quad (7)$$

In Eqs. 6 and 7, the several groups of delays are not indicated. We will use five groups in the subsequent analysis so that Eqs. 6 and 7 become

$$\frac{dn}{dt} = \frac{\delta k}{l^*}\, n - \frac{\beta}{l^*}\, n + \sum_{i=1}^{5} \lambda_i C_i e^{\tau K} \quad (8)$$

$$e^{\tau K}\, dC_i/dt = n\beta_i/l^* - \lambda_i C_i e^{\tau K} \quad (9)$$

In the experiment we bring the reactor to a specific power level and keep it at this level long enough so that there will exist a neutron density n_0, and an equilibrium value of each delayed-emitter concentration C_{0i}. If the value of δk is then changed in a harmonic fashion, specifically as a cosine or sine with a frequency of ω radians/sec, there will be a similar harmonic variation in n and C_i, which we designate as n_1 and C_{1i}.

For the time variation in δk, let

$$\delta k \equiv \delta k_0 e^{i\omega t} \quad (10)$$

and for the time variation in neutron density

$$n = n_0 + n_1 \quad (11)$$

where n_0 is constant, and n_1 is the time-dependent increment.

For the time variation in delayed-emitter concentration

$$C_i = C_{0i} + C_{1i} \quad (12)$$

The values of n_1 and n_0 can be measured with a neutron-sensitive instrument, and we would expect that the amplitude of n_1 and its phase with respect to δk would both be dependent upon the value of ω.

From Eq. 7, the equilibrium value for C_i is found to be

$$C_{0i} = (n\beta_i/l^*\lambda_i)e^{\tau K} \quad (13)$$

To treat the equation and simplify

Table of Symbols

- $n(t)$ = neutron density (cm^{-3})
- v = average thermal-neutron velocity (cm/sec)
- Σ_a = macroscopic absorption cross section of reactor material
- Δ = Laplacian operator
- C_i = concentration of delayed-neutron emitters of ith group
- $c = \Sigma C_i$ = total concentration of delayed-neutron emitters at any time
- k_∞ = thermal neutrons produced per thermal neutron absorbed in infinite reactor
- k = thermal neutrons produced per thermal neutron absorbed in finite reactor
- $\lambda_i = 0.693/t_i$ (sec^{-1})
- $T_i = 1/\lambda_i$ = decay time of fission fragments of ith group (sec)
- τ = Fermi age (cm^2)
- T_0 = mean effective life of thermal neutrons for infinite geometry
- $L^2 = 1/3\Sigma_a\Sigma_t$ = diffusion length squared
- β_i = fraction of delayed neutrons from ith group
- $\beta = \Sigma\beta_i$ = total fraction of neutrons which are delayed
- l^* = modified mean effective neutron life for finite geometry
- n_0 = steady-state neutron density
- C_{0i} = steady-state concentration of fission fragments of ith group
- ω = oscillation frequency
- n_1 = time-dependent neutron density term
- C_{1i} = time-dependent terms of fission fragments of ith group

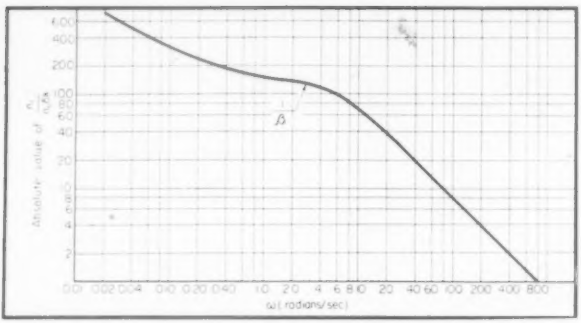

FIG. 4. Curve of amplitude response vs frequency for CP-2

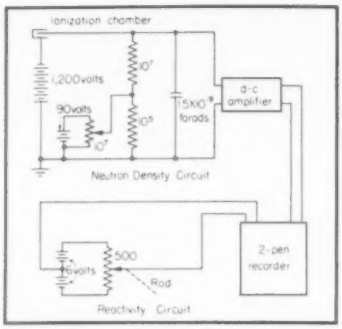

FIG. 5. Measuring circuits

notation, we will use the operator p as usually defined, that is $p = d/dt$ and $p^{-1} = \int_0^t dt$. Thus, from Eq. 9

$$e^{\tau k} p C_i = n_0 \beta_i / l^* - \lambda_i C_i e^{\tau k} \quad (14)$$

and, using Eqs. 11 and 12,

$$e^{\tau k} p C_{1i} = \beta_i (n_0 + n_1)/l^* - \lambda_i e^{\tau k}(C_{0i} + C_{1i})$$

The differentiation has been performed on the left-hand side of the equation. By using the C_{0i} value from Eq. 13, the equation can be reduced to

$$e^{\tau k} p C_{1i} = \beta_i n_1 / l^* - e^{\tau k}\lambda_i C_{1i}$$
$$e^{\tau k} C_{1i} = \beta_i n_1 / l^*(p + \lambda_i) \quad (15)$$

Equation 8 can now be rewritten in operational form, remembering that δk is now a function of time. Thus

$$l^* p n_1 = \delta k n_0 + \delta k n_1 - \beta n_0 - \beta n_1 + l^* \Big[\sum_{i=1}^{5} \lambda_i C_{0i} + \sum_{i=1}^{5} \lambda_i C_{1i} \Big] e^{\tau k}$$

Now, if the magnitude of δk is restricted to a value very much less than $\beta \approx 0.0076$, actually of the order 0.0005, the resulting magnitude of n_1 will be small compared to n_0. The numerical results will not, therefore, be much in error if these restrictions are met and the $\delta k n_1$ is neglected in comparison to the term $\delta k n_0$. Thus

$$l^* p n_1 = \delta k n_0 - \beta n_0 - \beta n_1 + l^* \Big[\sum_{i=1}^{5} \lambda_i C_{0i} + \sum_{i=1}^{5} \lambda_i C_{1i} \Big] e^{\tau k} \quad (16)$$

Equation 16 can be rewritten, using Eqs. 13 and 15, as

$$l^* p n_1 = \delta k n_0 - n_0 \sum_{i=1}^{5} \beta_i - n_1 \sum_{i=1}^{5} \beta_i + n_0 \sum_{i=1}^{5} \beta_i + n_1 \sum_{i=1}^{5} \frac{\lambda_i \beta_i}{(p + \lambda_i)}$$

which can be reduced to

$$p n_1 = \frac{\delta k}{l^*} n_0 - \frac{n_1}{l^*} \sum_{i=1}^{5} \frac{p \beta_i}{(p + \lambda_i)} \quad (17)$$

Then, in basic transfer function form,

$$\frac{n_1}{n_0 \delta k} = \frac{1}{l^* p} \left[\frac{1}{1 + \frac{1}{l^*} \sum_{i=1}^{5} \frac{\beta_i}{(p + \lambda_i)}} \right] \quad (18)$$

$$n_1 \cdot n_0 \delta k = (1 \cdot p l^*) \times \left[\frac{\pi_{i=1}^{5}(p + \lambda_i)}{\pi_{i=1}^{5}(p + \lambda_i) + \sum_{i=1}^{5} \frac{\beta_i \pi_{i=1}^{5}(p + \lambda_i)}{l^* \quad (p + \lambda_i)}} \right]$$

$$\frac{n_1}{n_0 \delta k} = \frac{1}{p l^*} \frac{\pi_{i=1}^{5}(p + \lambda_i)}{\pi_{k=1}^{5}(p + \alpha_k)}$$

The α_k are determined by formally carrying out the above indicated numerical operations. The results for particular values of β_i and λ_i, with $l^* = 1.25 \times 10^{-3}$, are given in the table below (3).

The resulting steady state equation, with $j\omega$ substituted for p in the usual manner, is

$$\frac{n_1}{n_0 \delta k_0} = \frac{(j\omega + 14)(j\omega + 1.61)(j\omega + 0.456) \times (j\omega + 0.154)(j\omega + 0.0315)}{j\omega l^* (j\omega + 14.4)(j\omega + 5.91) \times (j\omega + 1.41)(j\omega + 0.32)(j\omega + 0.08)} \quad (19)$$

which is plotted in Fig. 4.

Transfer-Function-Equation Constants

i or k	β_i (%)	λ_i	α_k
1	0.029	14.00	14.40
2	0.084	1.61	5.91
3	0.240	0.456	1.41
4	0.210	0.154	0.32
5	0.166	0.0315	0.08

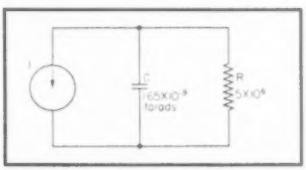

FIG. 6. Equivalent circuit for ion chamber

Experimental Apparatus

The reactor, which has low leakage, approximates an infinite pile, and has a mean effective neutron lifetime of 1.25×10^{-3} sec.

The reactor core is a 17 × 17 × 15-ft lattice, surrounded by a 16-in. graphite reflector and a 4-ft concrete biological shield, as shown in Fig. 1.

The device used to vary reactivity consisted of a 6-in. movable cadmium rod inside a 6-in. stationary cadmium cylinder, as shown in Fig. 2.

For maximum effect, the oscillating rod and stationary cylinder were placed near the center of the reactor core. The cadmium rod was attached to the end of an aluminum rod, and the aluminum rod was spring loaded. Oscillatory motion was transmitted to this rod through a ball bearing mounted on the rod and driven by a cam attached to a variable-speed drive. This assembly, shown in Fig. 3, provided the means for obtaining a rod displacement essentially sinusoidal with time.

Wherever possible, the rod apparatus was made of aluminum and the steel members did not extend beyond the biological shield. The entire apparatus inside the reactor was surrounded by graphite to prevent neutron streaming and minimize neutron flux distor-

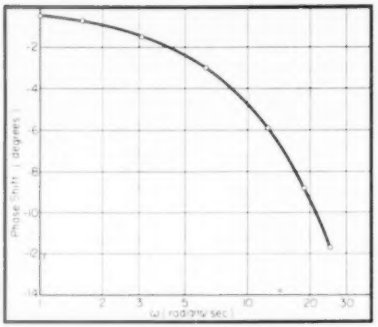

FIG. 7. Phase shift of ion-chamber circuit

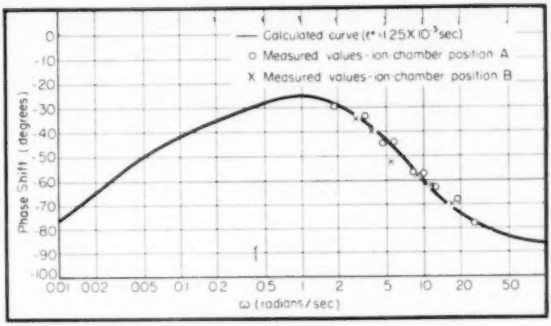
Calculated curve (t* = 1.25 X 10⁻³ sec)
o Measured values - ion chamber position A
x Measured values - ion chamber position B
Phase Shift (degrees)
ω (radians/sec)

FIG. 8. Phase-shift response vs frequency for CP-2

tion. One of the graphite blocks used for this purpose is shown above the cadmium oscillator in Fig. 2.

The circuit of the apparatus used for recording δk and n_1 is shown in Fig. 5. Each pen recorder and its amplifier had a combined frequency response that was flat from 0 to 100 cycles/sec.

The frequency response of the chamber circuit was determined at 4 cycles/sec, which was the maximum frequency used in this experiment. For this calculation, the ion chamber was assumed to be a constant-current source. The equivalent circuit is shown in Fig. 6. The capacitor C represents the combined capacity of the chamber, leads, and a 1,500-$\mu\mu$f capacitor, making C equal to 1,650 $\mu\mu$f.

The resistor R in Fig. 6 is the parallel combination of the 10×10^6-ohm resistor shown in Fig. 5 and the 10×10^6-ohm input impedance of the amplifier, or 5×10^6 ohms. The response of this circuit at any frequency is the ratio of the output voltage at that frequency to the output voltage at zero cycles/sec. Designating this as the gain of the circuit, we have

$$\text{gain} = \frac{\dfrac{R/j\omega C}{R + 1/j\omega C} I}{RI} = \frac{1}{1 + j\omega CR} \quad (20)$$

For the 4-cycle case, with the above values of C and R, this becomes

$$\text{gain} = 0.959 - 0.198j \quad (21)$$

The amplitude response is given by the absolute value of the gain, which in this case is 0.978 or, in decibels,

$$\text{gain} = 20 \log 0.978 = -0.18 \text{ db}$$

This value is within the range of experimental accuracy, and it was therefore assumed that the circuit had a flat amplitude response over the range of frequencies used in this experiment.

The phase angle, ϕ, of the ion-chamber circuit can also be obtained from Eq. 20. At four cycles, using the results of Eq. 21, this is

$$\phi = \tan^{-1}\left(\frac{-0.198}{0.959}\right) = -11.7 \text{ degrees}$$

This figure is outside the range of experimental accuracy, and therefore the phase-shift curve of the circuit was calculated and the curve of Fig. 7 obtained. This was applied as a correction to the experimental data before plotting the curve shown in Fig. 8.

In the neutron-density circuit (Fig. 5), the 90-volt battery, 10×10^6-ohm potentiometer, and 100×10^3-ohm resistor were used to cancel out the large steady signal due to the variation of the neutron density about the absolute value of n_0.

For recording the applied time variation in reactivity, or δk, the arm of the potentiometer in the reactivity circuit (Fig. 5) was attached directly to the oscillating rod. This arrangement is shown in Fig. 3. A voltage proportional to rod displacement was fed directly into one pen recorder.

The chamber used in this experiment was of the annular type filled with enriched BF_3 gas, and had an active region of $12 \times 4 \times 1\frac{1}{2}$ in. This chamber was inserted in the reactor as shown in Fig. 3, and data taken at the two positions in this hole shown in Fig. 1. The reactor hole was plugged with 18 in. of graphite and 4 in. of lead to shield personnel from radiation and to minimize neutron flux distortion near the chamber.

To check the linearity of the chamber, it was calibrated against reactor power, see Fig. 9. This curve shows good linearity in the region of 8–9 μa output in which the chamber was used. The variations in output were very small and therefore the chamber output was, for all practical purposes, linear with respect to pile power, or neutron density, for the experiment.

Experimental Procedure

The reactivity was varied sinusoidally with time by oscillating the cadmium rod about its mean position. Experimental data were obtained at a number of frequencies of oscillation for each of two chamber positions. With the chamber in position A (Fig. 1), the reactor was operated at 1,000 watts, and with the chamber in position B it was operated at 500 watts.

The frequency was varied by changing the cam speed at the speed reducer. Data were taken at discrete frequencies.

Both the n_1 measurement and reactivity measurement were fed into the 2-pen recorder. The recorder chart therefore showed the measurement of phase shift between the reactivity variation and the n variation, as well as the variation of the amplitude of n_1 with frequency. The amplitude of reactivity change was kept constant throughout this experiment. The frequency of the input was read directly from the recorder chart.

It was necessary to keep the magnitude of variation of δk small to provide the best comparison of experimental results with the calculations. A small δk value was necessary for mathematical simplification as shown before. A 1-in. stroke of the oscillating rod was used. The peak-to-peak value of this sinusoidal reactivity variation was found by measuring reactor period.

The reactor was stabilized at critical when the rod was at its furthest posi-

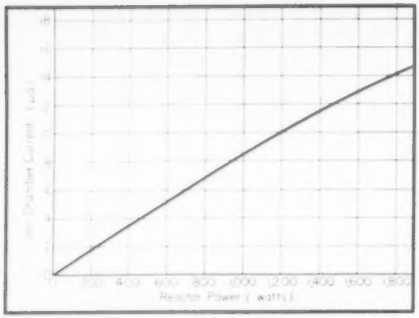

FIG. 9. Ion-chamber current vs reactor power

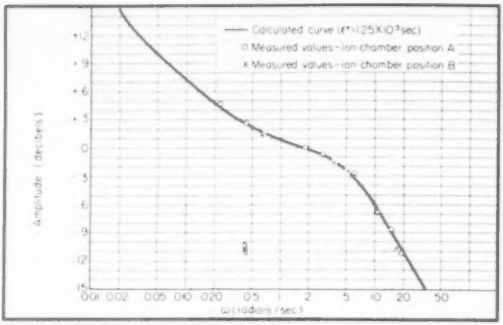
Calculated curve (t*=1.25X10⁻³sec)
o Measured values - ion chamber position A
x Measured values - ion chamber position B
Amplitude (decibels)
ω (radians/sec)

FIG. 10. Amplitude response vs frequency for CP-2

tion in the reactor ($^1/_2$ in. from center) and then the rod was quickly moved to its furthest position out ($^1/_2$ in. the other side of center).

The time for the neutron density to rise a factor of e was noted, and the associated reactivity change was computed to be 1.4 inhours (barometric pressure corrections were negligible). The amplitude of the sinusoidal reactivity used in this experiment was, therefore, 0.7 inhours, or $\delta k = 1.82 \times 10^{-5}$. This follows from $\delta k = 2.6 \times 10^{-5}$ times the number of inhours.

The amplitude-response data are plotted in Fig. 10 along with the calculated curve. These values are shown in decibels and to relate them to absolute values, the gain, in terms of $n_1/n_0\delta k$, was determined at 3.7 radians/sec. Since δk was known, there remained the problem of determining n_1/n_0. Both n_1 and n_0 were present as voltages, n_1 being the amplitude of the sinusoidal variation that was superimposed upon the very much larger d-c signal, n_0.

The voltage corresponding to n_0 was measured by placing a resistance of 5×10^6 ohm in series with the chamber and 1,200-volt battery, and measuring the voltage developed across the resistance with a very-high-input-impedance voltmeter ($5{,}000 \times 10^6$-ohm input impedance).

This circuit was also used to obtain the chamber calibration curve shown in Fig. 9, in which case the pile power was determined from a master chamber and galvanometer system for which power calibrations had been made.

The voltage corresponding to n_1 was determined by feeding a 60-cycle voltage from a low-impedance source into the amplifier to obtain the same pen deflection as produced by n_1, and then measuring this 60-cycle voltage with a voltmeter. Knowing $n_1/n_0\delta k$ at any particular frequency, this value can be compared with the calculated value of $n_1/n_0\delta k$ as plotted in Fig. 4.

In measuring phase shift at any one frequency, the horizontal distance that the δk peak was displaced from the n_1 peak was measured on the recorder chart. The phase angle is the ratio of this distance to the distance between two δk peaks, or two n_1 peaks, multiplied by 360 degrees. From these values, the phase shift of the ion-chamber circuit, Fig. 7, was subtracted.

The calculated phase-shift curve is shown in Fig. 8 together with some experimental values. The accuracy of these experimental values ranged from ± 5 to ± 10 degrees, due to the difficulty in reading the peak positions on the recorder chart. This difficulty resulted from several factors.

This experimental uncertainty resulted from the fact that the input, or reactivity, variation was not truly sinusoidal, and that the reactivity-measuring circuit did not have a voltage output always exactly proportional to rod displacement. The combination of these two errors distorted the peaks of the reactivity signal on the recorder chart and made an accurate reading difficult. The fluctuations of the n_1 signal due to statistical variations and to noise obscured the peaks of the n_1 signal, adding to the difficulty of phase determination.

Comparison with Theory

To compare the calculated amplitude curve with experimental data it is only necessary to consider the shape of the curve. For the phase shift, the magnitude is absolute and a comparison can be made directly, point by point.

The curve of Fig. 4 can be replotted on a decibel basis, thus eliminating the absolute gain of the reactor which was plotted as the ordinate in this figure. This was done for Fig. 10 and the value 136.5 was chosen, for convenience, as 0 db. This is the point of inflection of the curve in Fig. 4. Then for Fig. 10, decibels equals $20 \log_{10} E/136.5$, where E is the ordinate of Fig. 4 for any particular ω.

The reactor gain, $n_1/n_0\delta k$, was measured at 3.7 radians/sec, which is the frequency at the point of inflection, and corresponds to the above 0 db value. In taking the data, the magnitude $n_0\delta k$ was held constant and the magnitude of n_1 was measured at various frequencies. Therefore, the experimental points shown in Fig. 10 are

$$20 \log_{10} R \text{ decibels}$$

where R is the ratio of the amplitude of n_1 at a particular frequency to its amplitude at $\omega = 3.7$ radians/sec.

Thus, the experimental data and the calculated data are referred to the same scale, and a comparison of the shape of the curves can be made. It is seen that the experimental points plotted in this way fall close to the calculated curve.

In the case of phase shift, the value is simply measured and plotted. The points shown in Fig. 8 correspond closely with the calculated curve, but are subject to the experimental error pointed out in the section on procedure.

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3. Table 3 of reference 2

Discrimination Against Noise in Scintillation Counters

The gating system described depends for its efficiency on phosphors with particular decay rates. It offers the convenience of a gamma counter that requires no cooling and in which photomultiplier noise is reduced by a factor of 250 at normal operating voltages

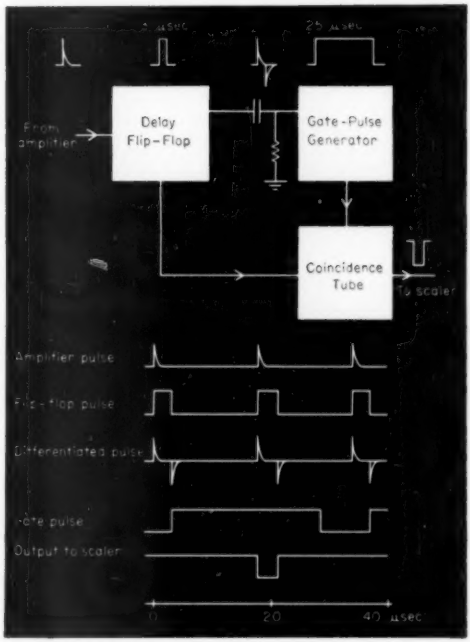

FIG. 1. Circuit diagram and pulse shapes

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One of the disadvantages associated with scintillation counters is the presence of a very large background, due mainly to thermal emission from the photomultiplier cathode.

Cooling the photomultiplier to a temperature near absolute zero is one way to reduce the effect of this background, but frequently such treatment is inconvenient (*1*). An alternative to removing the *cause* of the background noise is to devise a method of discriminating between the groups of pulses arising from scintillations and the randomly distributed noise pulses.

The two discrimination methods in popular use are the pulse-amplitude and coincidence-circuit methods. Both, however, have drawbacks for gamma counting, as discussed later.

This paper describes a discrimination method that seems more efficient than either of those just mentioned; with it, the noise counting rate can be greatly reduced with only a small loss of signal counts. The discriminator depends on a gating circuit arranged so that a count is registered only if two or more pulses appear at the output of the photomultiplier within 3 to 28 microseconds. Noise pulses rarely

occur with this particular spacing, but, because of it, only phosphors with a suitable decay rate can be used. Scheelite, for instance, is such a crystal; 65% of its scintillations occur within the 3–28 μsec time limit.

Pulse-amplitude discrimination has been used with success in alpha- and beta-ray counters where the amplitude of the signal pulses can be made large compared with the noise by proper choice of crystal and optical system. In gamma-ray counters, however, the signal pulses are, on an average, little greater than the noise and some signal pulses will be smaller than noise pulses. Amplitude discrimination is therefore only partially effective. To reduce the background count to a workable level, many of the signal pulses must also be eliminated. Under these conditions, the number of signal pulses counted will depend on the amplification, which varies extremely rapidly with multiplier voltage. The accuracy of counting then becomes very dependent on the constancy of the high-voltage supply.

With coincidence circuits, two or more photomultipliers are mounted in such a way that the scintillations from a single crystal strike the cathode of each. A count is registered only when pulses occur simultaneously at the output of all photomultipliers (3). If it is necessary to count small pulses, e.g., in the detection of gamma rays, a separate, wide-band amplifier must be provided for each photomultiplier.

Marshall, Coltman, and Bennett (3), using silver-activated zinc sulphide, made use of the phosphorescent effect in this material to improve on amplitude discrimination. A scintillation initiated by a single fast electron results in the emission of several photoelectrons from the cathode spread over an appreciable interval of time depending on the decay time of the phosphor used. The resulting group of pulses appearing at the output of the photomultiplier is significantly different from the randomly distributed noise and may be selectively amplified by proper amplifier time constants. A similar effect has been observed when using a Scheelite crystal, the decay-time constant being of the order of 10 μsec (4).

The mechanism of the discrimination method described in this paper is similar to that of the coincidence methods and may be described as a "delayed coincidence," the phosphorescence of the crystal in effect replacing the second photomultiplier in characterizing the signal.

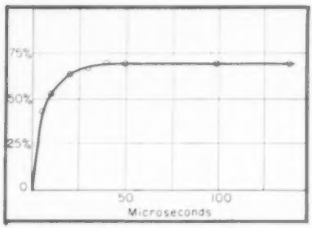

FIG. 2. Signal counting rate for various gate widths expressed as a percentage of counting rate with no discrimination

Description of Circuit

The general arrangement of the discriminator is shown in Fig. 1. The output of the photomultiplier is connected to a wide-band amplifier to obtain amplified pulses about 0.5 μsec wide. These pulses operate a "flip-flop" trigger circuit producing a square pulse about 3 μsec wide. The trigger circuit is designed to have a short recovery time. The triggered pulse is differentiated so that the gate-pulse generator can be operated on the "back edge" of the pulse. The generator produces a pulse that is delayed by 3 μsec. It can be varied in width from 5 to 200 μsec to test the effect of different gate widths. (It will be shown later that 25 μsec was found to be the most suitable gate width.)

Positive pulses from the first trigger circuit and from the gate-pulse generator are fed separately to the grids of a coincidence tube, whose output is applied to a scaler.

An incoming pulse of sufficient amplitude to operate the first trigger circuit will cause the gate to be opened after 3 μsec for a period depending on the setting of the gate-pulse generator. A second incoming pulse operating the first trigger circuit during this period will cause the coincidence tube to conduct and a count will be registered by the scaler. Since the resolving time of the scaler is set to 300 μsec, only one of these incoming pulses will be registered.

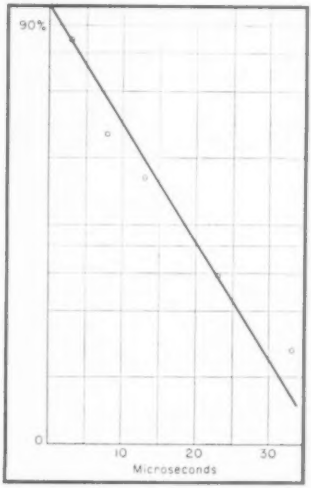

FIG. 3. Percentage of scintillations producing a second pulse after a given time interval

Effect on Noise

The noise pulses appearing at the output of the amplifier are variable in amplitude and have a width determined by the time constant of the amplifier—in this case about 0.5 μsec. If it is assumed that the pulses are randomly distributed, then the fraction passing through the gate may be calculated in the same way as the loss of counts due to deadtime in Geiger-Müller tubes (5).

If noise pulses arrive at the rate of p per second and the gate pulse width is t seconds ($t \ll 1/p$), a fraction pt will be recorded, i.e., p^2t counts per second.

To test the effect of the discriminator on noise pulses, the counting rate was first measured with the gate permanently open, then for various widths of gate pulse. The counting rate increased linearly with gate-pulse width and the noise reduction factor was in good agreement with the calculation.

Effect on Signals

To test the effect of the discriminator on the signal counts, the counting rate due to one gram of Scheelite irradiated by one milligram of radium at one meter was measured for several gate widths and expressed as a percentage of that obtained with no discrimination.

The resultant curve, plotted in Fig. 2, rises to a maximum of 70%, and there is no measurable increase beyond 50 μsec. Thus it was concluded that the

remaining 30% of the scintillations did not produce detectable pulses after the 3-μsec delay.

If this is so, then the curve can be replotted to show the percentage of scintillations producing a second pulse after a given time interval. As seen in Fig. 3, the curve indicates an exponential decay with a time constant of approximately 8 μsec and appears to be in agreement with the decay time of Scheelite measured by others (*4, 6, 7*), but rather shorter than the value stated by Belcher (*8*). Then, for minimum loss of signal counts consistent with good noise reduction, the delay time should be as short as possible and the gate width about 25 μsec.

Using these values, the effect of varying the multiplier voltage was measured to find the best operating conditions. Since the noise level with no discrimination was high, satisfactory measurements could not be made at room temperature.

For measurements of signal counting rate with no discrimination the photomultiplier and crystal were cooled in liquid air. A few measurements at low gain were repeated at room temperature. The measurements with the discriminator operating were made under both conditions.

Figure 4 seen at the right shows the resulting curves.

There appeared to be a slight increase of signal counting rate with cooling (*9*).

When no discrimination was employed, the counting rate rose rapidly with increasing photomultiplier voltage until a plateau was reached where presumably nearly all the scintillations were counted (curve A). Using discrimination, with a 25-μsec gate, a similar curve (curve B) was obtained which rises to a maximum of 65% of curve A, the remaining 35% of the signals being lost in the discriminator. The expected loss in the discriminator, assuming a decay time constant of 8 μsec for the phosphor, is 34%.

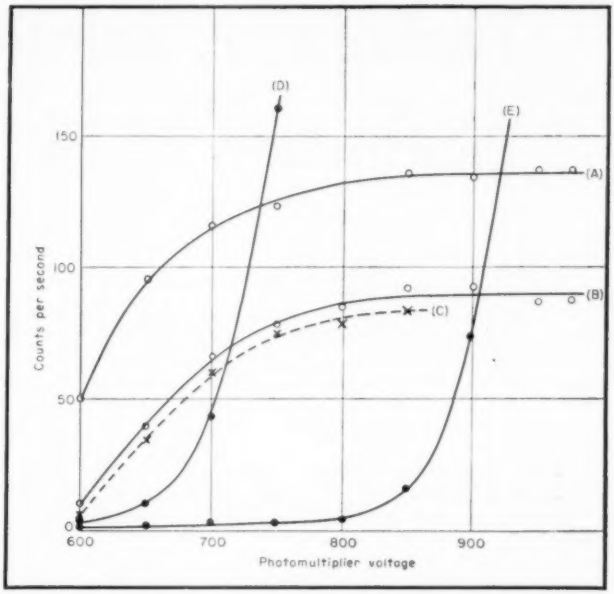

FIG. 4. Measurements of signal counting rate and background under various conditions, as follows:

(A) Signal counting rate with no discrimination at liquid air temperature
(B) Signal counting rate with 25 μsec gate at liquid air temperature
(C) Signal counting rate with 25 μsec gate at room temperature
(D) Background with no discrimination at room temperature
(E) Background with 25 μsec gate at room temperature

Application

The circuit described was developed for use in clinical tracer studies of gamma-ray emitters. In such applications, high efficiency and small detecting volume make a scintillation counter preferable to a Geiger-Müller counter (*9*). To obtain consistent results, it is necessary for the signal counting rate to be virtually independent of photomultiplier voltage and for the background counting rate to be low. The optimum working point is a compromise between these two requirements and may be determined from curves such as in Fig. 4.

Thus, for the photomultiplier used (RCA 931A) operating at 750 volts, the slope of the signal curve is 0.25% per volt with a background of 2 counts per second (less than 0.5 counts per second of this is due to noise). A similar performance has been obtained with three out of five photomultipliers.

It will be noted that the noise with discrimination varies as the square of the noise without discrimination. Thus a small reduction in photomultiplier dark current may make a large improvement in performance.

The more recent photomultipliers now available [e.g., EMI 5060 (*10*) and RCA 5819] are claimed to have a low dark current. By using these tubes in conjunction with the method of discrimination described, it appears possible to operate a scintillation counter satisfactorily at normal room temperature so that the counting rate due to noise is small compared with that due to radiation background.

* * *

" *The author wishes to thank Dr. J. S. Fulton, Medical Director of the Liverpool Radium Institute, for his encouragement in this work and Messrs. Murex, Ltd., for supplying a quantity of Scheelite.*

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Techniques Related to Production of Fe^{59}

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IN CONNECTION WITH methods for producing the iron isotopes Fe^{55} and Fe^{59} described in a companion article† in last month's NUCLEONICS, it was pointed out that cyclotron production of Fe^{59} from cobalt by the Co^{59}-$(d,2p)Fe^{59}$ reaction is the only convenient means of obtaining Fe^{59} in an approximately carrier-free condition.

From experience gained in preparing twelve samples of Fe^{59} from cobalt irradiated in the 60-inch Berkeley cyclotron, certain procedures are outlined here which may be combined or further refined into an established technique for producing and meeting the growing needs for high-specific activity Fe^{59}.

The steps in purifying cobaltous chloride for electroplating on the probe target have already been outlined.† How this cobalt target metal is fixed to the probe is described in what follows.

Preparing the Probe Block

Water-cooled probes are standard equipment for cyclotron targets, and are frequently rotated during bombardment to distribute the heavy heat load that must be dissipated. These probes are tangentially introduced into the cyclotron tank at the outermost periphery of the beam orbit, thus permitting the use of far greater bombardment currents than would be obtained if the beam were brought through a window to an external target.

Details of the $1\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{2}$ in. probe block actually used are not included here, since this particular block is limited to use in the 60-inch Berkeley cyclotron, and, furthermore, is supplied by this laboratory as part of the bombardment service. Unfortunately, there is no provision for rotating the probe in this cyclotron, so that full advantage may not be taken of the maximum beam which is available; namely, some 600 μa.

The method described here of fixing the cobalt target metal to the probe may be used with any cyclotron probe block. It will also do for many other electroplated metals.

The surface of the electroplated metal, as shown in Fig. 1, is usually uneven; infrequently it is quite rough as well. The cobalt itself is dense and massive, between 0.008 and 0.010-in. thick in the center. The depressions on this surface are not readily cleaned with acid without dissolving appreciable amounts of the exposed metal. To obtain a satisfactory surface, which will be almost completely wetted by the solder, it is best to use a high-speed cloth wheel.

FIG. 1. Uneven surface of electroplated cobalt shown here has been partly smoothed on sander prior to fixing to the cyclotron probe block

Before fitting them together, the cleaned cobalt surface and the face of the copper probe block should be tinned with Easy-flo silver solder, leaving an excess on each. The tinned surfaces are then placed in contact and pressed firmly together while being heated with a torch. After cooling, the four sides are roughly squared on a belt sander, to remove the excess solder and provide better surfaces for subsequent machining operations.

The $\frac{1}{4}$-in. copper electroplating block is next milled away, or infrequently, may be pried off. The milling operation should be stopped when the cobalt surface is just reached. The final removal of the copper, plus the first one or two thousandths of an inch of cobalt, should be accomplished with a surface grinder. Since the surface of the cobalt in contact with the original copper cathode will not usually be exactly parallel with the back of the probe block after soldering, the first cuts with the grinder should be across the thickest part of the remaining copper. Following this, either the copper may be ground away in a step-wide manner, or the block should be relocated so that the wheel will grind the copper with a minimum of cobalt.

After finishing the cobalt surface, and before use, the whole block should be thoroughly cleaned by immersion in boiling water. If this is not done, small amounts of sodium salts from the soldering flux will remain with the target and, during bombardment, pro-

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† See "Methods of Producing Radio-iron," by Rayburn W. Dunn, NUCLEONICS **10**, No. 7, 8 (1952)

From methods devised for preparing high-specific-activity Fe^{59} by the cyclotron (*d*,2*p*) reaction with cobalt, various techniques have evolved for treating the probe block before and after irradiation and for preparing the purified Fe^{59} for medical use. Purity and yields are discussed

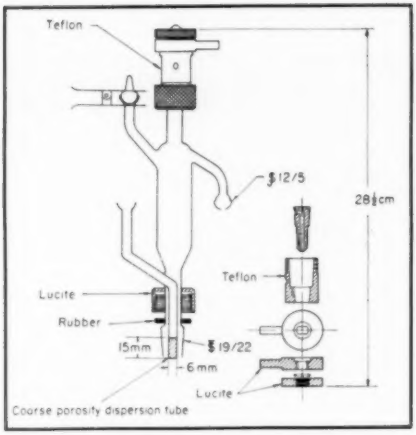

FIG. 2. Details of ether extraction cell

duce considerably greater amounts of contaminating radioactivity than come from the iron and cobalt together.

Finally, the block, and particularly the cobalt surface, should be cleaned with hydrochloric acid for removal of external iron. The cobalt should be additionally etched to a depth of about 0.001 in. with nitric acid to remove any iron that may have been embedded from the grinding wheel.

Removal of Activity

After bombardment, manipulations with the activated block should be carried out behind lead shields.

Originally, the method for removing activity from the cobalt surface was to mill it off with a milling machine used only for the handling of hot targets. However, aligning the target surface so that maximum recovery could be obtained with minimum cobalt was exceedingly difficult and involved excessive exposures of personnel to radiation. This procedure was consequently abandoned in favor of one involving removal by acid and less exposure to radiation.

Since the (*d*,2*p*) reaction occurs only at or above beam energies in the neighborhood of 18 Mev and the incidence of beam to the target is about 10 degrees from grazing, the Fe^{59} will be produced only at or close to the surface of the cobalt. Thus it is necessary to remove cobalt to a depth of only about 0.001 in. for complete, or nearly complete, recovery of the radioiron.

A thickness of 0.001 in., dissolved from an area of $1\frac{1}{2} \times 2\frac{1}{2}$ in., yields about 1 gm of cobalt. It was found that 50 ml of 1*N* nitric acid will dissolve the stoichiometric amount of cobalt, i.e., about 1.1 gm from this amount of surface if left in contact for a sufficient time. This was the procedure adopted for removal of the active surface layer.

Unfortunately, there is no way of checking to make sure that the cobalt surface is not selectively attacked by the acid. One target was actually treated twice with acid and the activity in the second fraction was estimated by its radiation level to be about $\frac{1}{10}$ of the first, but this sample was inadvertently discarded before a radioactivity assay could be made on it. It must be assumed that the area which actually receives the maximum beam is attacked by the acid at a rate which is not less than the rate of attack in other areas, and this assumption is probably valid.

The container in which the cobalt is dissolved is a specially made beaker with beaded lip but no pouring spout. It has an inside diameter of 3-3$\frac{1}{4}$ in. and should be provided inside with a rubber pad of nearly the same diameter. Like all equipment with which the cobalt solution must be in contact, these items must be clean and free of iron.

The probe block is introduced face up into the beaker and carefully placed on the rubber pad.

A heavy lead block about 4 in. long with a $1\frac{1}{2} \times 2\frac{1}{2}$ in. face on one end and a long handle on the other is provided with a $1\frac{7}{16} \times 2\frac{7}{16}$ in. soft rubber pad that is glued to and covers the face. To facilitate cleaning and, later, decontamination, the lead block is placed face down on a piece of clean polyethylene sheet which is then carefully folded up so that no creases occur on the face, and fastened to the handle or upper part of the block with Scotch tape. Polyethylene was actually used, but it is recommended that some other plastics be tried because paraffin sticks to it and makes the following operations somewhat difficult.

The plastic-covered rubber face is next placed against the cobalt surface and aligned as well as is possible by observing in mirrors behind the shield.

Molten paraffin from an electrically heated aluminum pouring pot is then introduced through a funnel made of heavy waxed paper. The bottom of the funnel should be so placed that the liquid will pour either on the rubber pad at the bottom of the beaker or against the wall of the beaker near the bottom. It should not be poured on the plastic-covered block. Also, it should be above the level of the cobalt so that the funnel will not be embedded in the paraffin when the latter solidifies. The embedding material should be quite hot to allow it to flow evenly around the cold copper. A sufficient amount of it should be added to bring the level a slight distance above the surface of the cobalt.

Before removing the protecting block, the paraffin should be allowed to cool to room temperature. Otherwise the paraffin may pull away from the edges of the probe block.

When the embedding is completed 50 ml of 1*N* nitric acid are introduced

into the beaker. For agitation, a glass stirrer is used that is inserted in a small hole drilled in the center of a solid watch glass and fixed in the chuck of an electric motor. It is rotated just fast enough to keep the solution gently agitated. The acid should be allowed to react completely. This requires several hours.

The solution is removed from the beaker, together with a few milliliters of wash, and evaporated to dryness in a 200-ml tall-form beaker with a ribbed watch-glass cover. After cooling, the dry salt is carefully treated with 10 ml of iron-free concentrated hydrochloric acid and again taken to dryness. The beaker need not be cooled completely before adding each of the subsequent three or four 10-ml portions of HCl, but caution is called for to prevent its spattering.

The completion of conversion to chloride is determined by noting the presence or absence of the brown fumes reaction after each HCl addition to the warm dry salt. Additions should be continued until two are obtained from which no NO_2 evolutions are observed.

The cobaltous chloride is next dissolved in 25 ml of iron-free 8*N* HCl and transferred to a six-unit ether-extraction apparatus. One cell is seen in Fig. 2. The assembled apparatus with six cells in series is seen in Fig. 3.

Originally built completely of glass, this apparatus has been modified and considerably improved to include specially designed Teflon valves at top and bottom. The Teflon valves have eliminated the leakage which developed with the glass stopcocks when under pressure during extraction.

The assembled apparatus is designed to fit in a standard glove box, together with a variable-capacity Teflon-lined diaphragm pump.

Before introducing the radioactive solution, the six units are mounted and connected as shown. The Teflon stopper-valves are closed at the bottom but left open at the top. The spherical joint stoppers are removed from the upper sidearms and 20–25 ml of iron-free 8*N* HCl are introduced through these openings into cells 2, 3, and 6, counting from left to right. A like amount of distilled water is placed in cells 4 and 5. Then sufficient washed isopropyl ether is individually introduced into these five cells to fill each to a level slightly above the effluent side arms on the right. Approximately the same volume of ether is placed in cell 1. The stoppers are placed in the side arms and clamped, as shown, omitting cell 1, and the upper valves are closed.

The radioactive solution is introduced into cell 1, and this cell is then stoppered and the valve closed. Additional ether is introduced, if needed to prime the pump, through the side arm of cell 6.

The pump diaphragm vibrates with small displacement at a rate of about 45 pulses per minute. The internal pump volume is between 1 and 2 ml. A tempered platinum wire spring is used to load the small Teflon flutter valves. The throughput is about 3 ml per minute.

In operation, the effluent ether from cell 6 travels out through the side arm at the right side and through the connecting tube leading from this cell directly to the pump. The holdup in this pump is negligible, since the internal volume is less than 2 ml; the flow is effectively direct from cell 6 to 1.

Each of the extraction cells, as shown in Fig. 2, is so constructed that the influent ether is introduced at the bottom of the cell through a sintered dispersion tube. In passing upward through the aqueous layer, it mixes, extracts, and passes to the next cell.

The ferric chloride is progressively removed from the first cell, the ether is washed to remove entrained and/or extracted cobalt and other inorganic salts in cells 2 and 3, and the iron is re-extracted into water principally in cell 4, with some in cell 5. Because the salt and acid concentration varies between cells, there is a constant transfer of water from the water extraction cells to the $CoCl_2$. This dilutes the $CoCl_2$ and decreases the efficiency of the process. To minimize this transfer, 8*N* HCl is placed in cell 6. Such an expedient is only partly successful, however.

Present procedure calls for two or three four-hour extractions, depending upon the amount of total iron, with a change of the water in cells 4 and 5 between extractions. Completeness of extraction is determined by monitoring all the several extraction cells except the first after each period. Little quantitative data are available to serve as a guide, and completion time of the process is more or less up to the judgment of the operator. Recovery may also be based on the activity of each of the removed water fractions.

A test run was made with the original all-glass apparatus, using reagent grade $CoCl_2$ in the first cell together with a tracer amount of Fe^{59}, 8*N* HCl in the next three cells, and water in the last two. The diaphragm pump in this test was set to circulate ether at about 7 ml per minute. After one hour of extraction, some 99% of the activity was removed from the cobalt and an estimated 95% was recovered from the combined acid and water cells. (This extraction was discontinued after the one-hour period because of pump failure. The cobalt solution was saved for subsequent tests, since it was considered to be nearly completely freed of its original iron impurity.)

Subsequent tests with known amounts of normal iron and tracer added to the cobalt solution and a flow rate of 4 ml/min gave results indicating recoveries from 96% with 0.7 mg of carrier to about 90% with 0.4 mg. Two extractions (of 2 and 3 hours) were performed in each case with the water replaced between extractions. Recovery data are for the combined water fractions.

Further quantitative data were not obtained before this apparatus was placed into use, and no test data were obtained with the modified apparatus and pump described and actually in use at the present time. A fair estimate of recovery from the latest runs is between 80% and 90%.

This apparatus would not successfully recover the radioactive iron if the amount of carrier were actually as low as indicated by the amount in the purified cobalt solution, i.e., 10μg from 1 gm of dissolved target cobalt. When originally designed, it was not known that the amount of impurity could be lowered to this extent. At later dates, with targets prepared from the highly purified cobalt, a sufficient amount of iron was always introduced at unknown times and from unknown sources, which permitted successful extractions.

Although a satisfactory performance has been obtained with the apparatus described, it is recommended either that a new design be attempted which would allow the use of much smaller volumes during extraction or that a new procedure be devised. This should be accomplished in anticipation of the time when full advantage may be taken of the ultimate carrier level achievable, as pointed out previously.

A straightforward approach to such a separation has been developed by Gile,* who used a cobalt target treated as described but on which only small amounts of Fe^{59} still remained. The metal surface was etched with 12*N* HCl to remove approximately 100 mg of cobalt, the solution centrifuged, and the supernatant removed. The solution was then neutralized with 15*N* NH_4OH to *p*H 9, and slowly filtered through Whatman No. 50 filter paper. The iron is stated to be quantitatively recovered on the filter paper, carrier-free.

Preparing Fe^{59} for Medical Use

The final solution containing the Fe^{59} plus small amounts of acid and ether has been processed by a variety of procedures, none of which could be safely applied if the total iron content were actually at the ultimate minimum, i.e., 10 μg.

In the presence of 0.1 mg or more of carrier, it is satisfactory to evaporate the solution to small volume, but not to dryness, to transfer it to a 10-ml centrifuge cone with the aid of a few drops of concentrated HCl as a beaker wash, and to precipitate the iron from not more than 3–4 ml of solution with concentrated ammonium hydroxide, which frees it of the major portion of the nonvolatile ether residues. The precipitated ferric hydroxide may be redissolved and reprecipitated as desired, and finally taken up in ammonium citrate for dilution, sterilization, and injection.

If lesser amounts of carrier are present, it is suggested that the solution, free of cobalt and other radioisotopes, be neutralized to a *p*H of 2.5–3.0 and the iron then absorbed batchwise on one or two 1-gm portions of 250–500 mesh Dowex 50 H-form cation resin. Because this resin is initially fairly high in iron, this iron must be removed with hydrochloric acid before use. After washing with water, the active material may be eluted from the resin with small volumes of 6*N* HCl, or may be removed directly into a complexing solution, from which dilutions may be made directly for medical usages.

With most of the high-specific-activity samples, the ferric hydroxide precipitation method has been used, but the relatively small amounts of iron have permitted the resulting ferric chloride to be combined directly with globulin fraction IV-7, after neutralization to *p*H 3.†

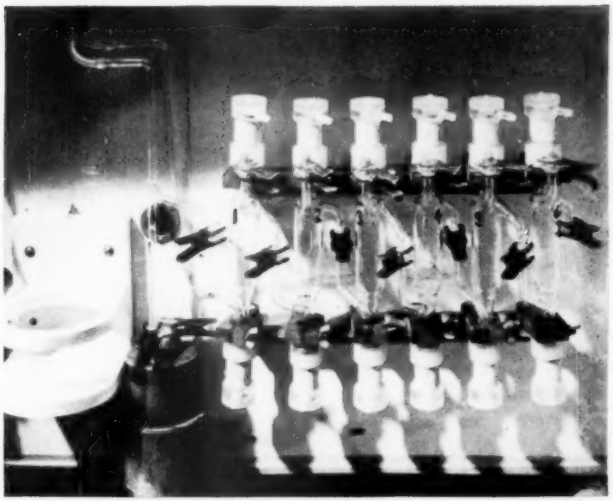

FIG. 3. Ether pump and assembled Fe^{59} extraction cells in glove box. Lead glass has been removed

Yields and Specific Activities

Four of the best runs made during the past year produced total yields of 1.8, 0.8, 1.5 and 0.5 mc. The respective specific activities were 11, 1.1, 3.1, and 3.9 μc/μg, and the corresponding total iron assays showed 0.16, 0.71, 0.38, and 0.17 mg. The bombardment efficiencies for the first three were 0.11, 0.07, 0.07 μc/μa-hr. The probe current data for the fourth sample are not available.

The radioassay data were collected using an end-window counter or a scintillation counter with reproducible geometry. Both counters were standardized against radioiron samples previously calibrated in a coincidence counter. The iron content of these samples was determined colorimetrically by the α,α-dipyridyl method.

From these data, the 60-inch cyclotron yield of Fe^{59} is estimated to be equal or greater than 0.07 μc/μa-hr of 20-Mev deuterons. The yield after 100 hours at 200–250 μa should be between 1.5 and 2 mc, and the maximum specific activity may be as high as 100 μc per μg of iron.

Radiochemical purity of the products was checked by plotting decay curves for the period during which the samples were being used. This was mostly not more than six months, or four Fe^{59} half-lives. No indications of Co^{60} or other radioactive contaminants were found during these periods.

* * *

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In addition, thanks are extended to C. A. Tobias, R. L. Huff, and the Donner Laboratory staff, for their help during the course of the work, and later for assisting in the collection of the necessary data, and to J. H. Lawrence for support and encouragement.

The author is also indebted to J. G. Hamilton, T. M. Putnam, and G. B. Rossi for assistance with bombardments in the 60-inch cyclotron, and for supplying bombardment data, and to N. Garden and the staff of the Radiation Laboratory Health Chemistry Division for helping with the extraction apparatus assembly and processing. W. G. Ruehle is credited with improving the original extraction apparatus and L. Deckard with designing the diaphragm pump.

* J. D. Gile, W. M. Garrison, J. G. Hamilton. Carrier-free radioisotopes from cyclotron targets, XVII—preparation and isolation of Fe^{59} from cobalt, UCRL-1315 (1951)

† R. L. Huff, P. J. Elmlinger, J. F. Garcia, J. M. Oda, M. C. Cockrell, J. H. Lawrence. Ferrokinetics in normal persons and in patients having various erythropoietic disorders, *J. Clin. Invest.* **30**, 1512 (1951)

TUBE CHARACTERISTICS

Multiplier Type		5037	4646
Number of Dynodes		10	16
Gain		10^6	10^7
Over-all Voltage		1,000 volts	2,000 volts
Cathode	Dimensions	3½ in. diam.	½ x 1 in.
	Sensitivity	30 – 50 μa/l	30 – 50 μa/l
	Spectral Type	S-9	S-9
	Collection Efficiency	High	High
Over-all Dimensions	Diameter	4 in.	1⅝ in.
	Length	7 in.	7½ in.

Two New Photomultipliers for Scintillation Counting

The type H-5037 tube is designed for efficient collection of light from a large crystal, and the type 4646, for counting events involving extremely short time intervals. Their design and applications are discussed

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THE RESULTS which can be achieved with a scintillation counter depend critically upon the characteristics of the photomultiplier employed. To meet some of the applications which place special requirements on the photomultiplier, the two tubes described here were designed and built on an experimental basis.

These two multipliers can be broadly classified as a large-area photocathode high-efficiency tube, the type H-5037, and a high-gain, large-output current tube, the type 4646.

The type H-5037 photomultiplier, Fig. 1, is useful for collecting a major fraction of the light produced in a large crystal, as in gamma-ray spectrometry. Here, the large crystal is required so that the radioactive sample can be completely imbedded in the phosphor, with the surrounding material thick enough to absorb all of the emitted radiation.

Scintillation counter measurement of high-energy particles is another example. Their low specific ionizing power, together with their great penetration, makes large phosphors essential.

The type 4646 tube, Fig. 2, finds application in a second important use of the scintillation counter, namely, the timing of nuclear events where extremely short time intervals are involved. If a conventional multiplier with a gain of around 10^6 were employed, the output pulses would be much too small to be used directly. It is necessary to amplify them with a high-gain, wide-passband amplifier before applying them to an oscilloscope or coincidence circuit. This necessitates the use of distributed amplifiers of many stages or other complicated amplifying systems. However, the type 4646, with a gain greater than 10^7 and high output current capabilities, operates the indicator directly.

It should be pointed out that chronographic measurement is only one of the applications of this high-gain tube. For example, the type 4646 lends itself to a small, portable survey-type instrument requiring no

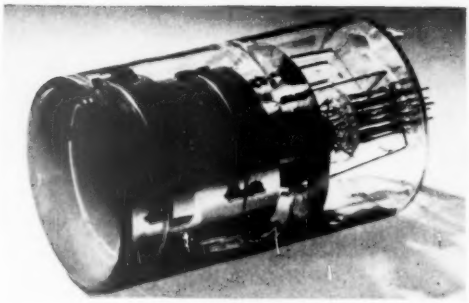

FIG. 1. Large-area-photocathode, high-efficiency photomultiplier, type H-5037

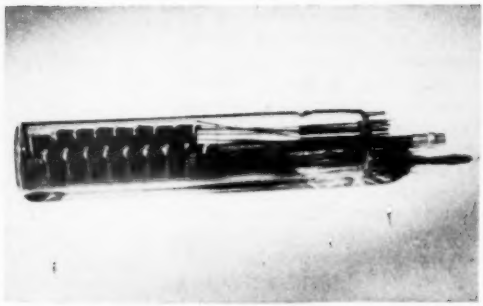

FIG. 2. High-gain, large-output-current photomultiplier, type 4646

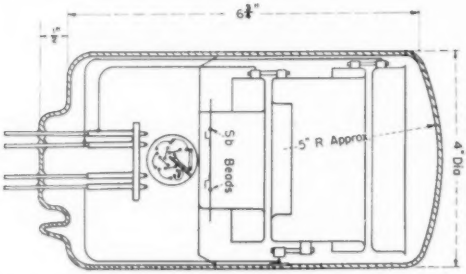

FIG. 3. Cross-sectional diagram of type H-5037

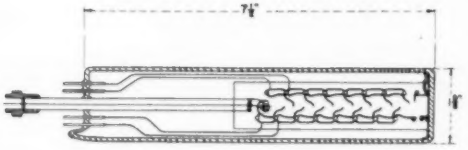

FIG. 4. Cross-sectional diagram of type 4646

amplifiers. It will also be useful where the photomultiplier is in a remote location, making it undesirable or impossible to have an amplifier directly associated with it.

Type H-5037 Tube

A diagram of the H-5037 is shown in Fig. 3. The photocathode on the end of the tube is sensitized with cesiated antimony. Its diameter is 3½ in., and the working area 9.6 in.^{2}

Important features of this tube are its very high efficiency and uniformity of photosensitivity and of photoelectron collection over the entire cathode. To insure uniformity of the photo surface, the antimony is evaporated from two beads placed very close to the center of curvature of the cathode.

High collection efficiency is obtained by the use of a rather elaborate electron optical system which directs electrons from the photocathode onto the first dynode. This system resembles in principle the lens system used in an image tube (e.g., the 1P25). The photocathode serves as object for the lens system, and the first dynode is placed at the exit pupil. This means that the position and size of the electron bundle striking the first dynode is independent of the position and size of the illuminating spot of light on the photocathode. In other words, a given scintillation will produce the same output charge irrespective of where the light strikes the photocathode.

The general arrangement of the various lens elements is shown in Fig. 3. The potentials are approximately zero volts on the first lens element, 200 or 300 on the second lens element, and 1,000 on the final element. Operation of the lens is affected, of course, only by the ratios of the various potentials. Since a high secondary emission ratio is very desirable at the first dynode in order to improve the statistics of the multiplier, it might seem better to operate the first dynode at the peak of its secondary emission ratio (approximately 500 volts for $SbCs_3$). It is found, however, that the small decrease in secondary emission ratio in going to 1,000 volts is more than compensated for by the increase in collection efficiency and the increased stability of operation. The multiplier itself, which is shown in the diagram, is of the 931 type with the element, which in the 931 is the cathode, serving as the first dynode of the H-5037. The sensitivity of the photocathode is the same as that of the 5819.

Type 4646 Tube

In describing the characteristics of the type 4646 photomultiplier (Fig. 4), it is convenient to divide the discussion into three areas: the multiplier structure, the photocathode and photoelectron collector system, and the anode output system. The tube is sensitized with cesium antimony and has spectral characteristics and quantum efficiency similar to the 5819.

Collector system. The photoelectron collection system is designed to have very high collection efficiency. Measurements indicate that the efficiency is between 95% and 100% over practically the entire area of the photocathode. The collector system is arranged to produce a high withdrawing field in the vicinity of the photocathode. This has the effect of

reducing the transit time between the photocathode and the first dynode. Accompanying the reduction in transit time, there is also a reduction in the transit time spread. In addition, the relatively strong field in the photocathode region makes the tube less susceptible to interference by stray magnetic fields.

Anode system. The anode system is arranged to deliver high currents so that reasonable voltage pulses can be obtained with the small load impedances necessary for the handling of very short-duration pulses. This anode system is capable of delivering about 200 ma of non-space-charge-limited current when operated with 200 volts between the 15th and 16th dynodes, and the 16th dynode and the anode.

To give the tube suitable electrical characteristics for high-speed work, the output leads are brought out in the form of a 125-ohm coaxial line. The outer conductor of this line is connected to the anode while the center wire is connected to the 16th dynode. A cable connector fitting is provided at the end of this line. The extra capacity introduced by this use of coaxial output is only about 2.8 $\mu\mu$f. This very small additional output capacity will not interfere with the application of the multiplier where the tube is working into high impedance loads.

Figure 5 shows two types of anode systems which have been used in these tubes. The first structure is better electrically than the second but is considerably more difficult to manufacture. A decision as to which should be adopted rests on further tests.

In the first system, electrons from the 15th dynode are directed onto the 16th dynode which is at the center of a grid-type anode collector. Electrons from the 16th dynode are picked up by the wires of this collector. The 16th dynode is fluted in order to direct the electrons onto the collector wires, thus minimizing the tendency of electrons to oscillate back and forth around the anode electrode.

In the second type of anode system, the 16th dynode is flat and the anode collector is in the form of a high-transmission grid. Electrons from the 15th dynode pass through the grid onto the 16th dynode, and the secondary electrons from the latter are collected by the anode. The fields at both the 15th and 16th dynodes are largely determined by the anode potential.

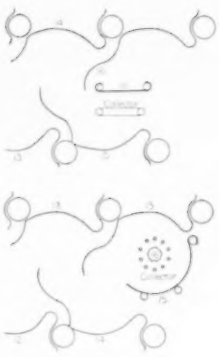

FIG. 5. Alternative anode structures of tube type 4646

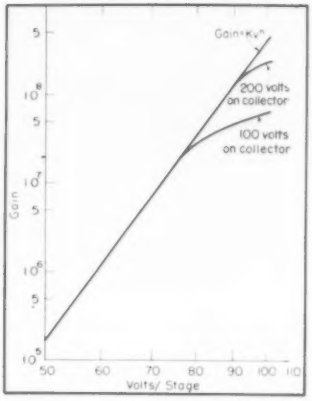

FIG. 6. Gain vs voltage of a high-gain multiplier with conventional anode structure

Since the spacings between these elements are small, fields high enough to eliminate moderate space-charge effects can be obtained with reasonable potentials on the electrodes. Part of the 16th dynode follows the shape of the regular dynodes used in the tube to retain focus between the 14th and 15th dynodes. The focusing portion of the 16th dynode is brought out on a separate lead and is not part of the coaxial system. Since current does not flow to or from this section of the electrode, it does not form part of the a-c output circuit. By isolating it from the latter, there is an appreciable decrease in the lumped capacity at the end of the coaxial line. Both anode systems are capable of delivering several hundred milliamperes when operated at a few hundred volts.

Space-charge considerations are the primary concern in the design of the anode system. If a simple anode, similar to the dynodes, were to be used in this type tube, the peak current which could be collected would be only 20 or 30 ma. At a gain of approximately 10^9, this would be entirely inadequate for any application where pulse-height measurements were involved, since the tube would saturate on less than one photoelectron from the photocathode. Figure 6 illustrates this point. Here, the gain plotted on a logarithmic basis is given as a function of the voltage per stage on the multiplier. (Since over the relatively small range of voltage variation the secondary emission ratio is essentially a linear function of the voltage, the mean curve should be a straight line.)

The shape of the line for a 16-stage multiplier corresponds to a power law with an exponent of 12. The smallest unit of charge which can leave the photocathode is, of course, a single photoelectron. Therefore, the smallest unit of current of the output will be one electron multiplied by the gain of the tube divided by the duration of the pulse. As the gain is increased, the current represented by a single electron gets larger and larger since the duration of the charge remains practically constant. This means that at some point the space-charge-limited current will be reached, and a further increase in gain will not give a corresponding increase in output.

From the figure it will be seen that for this 16-stage multiplier with a conventional anode at 100 volts, the change in slope of the gain curve begins to appear at about 77 volts per stage, or a gain of 2×10^7. At 200 volts on the collector, the point of change of exponent occurs at a gain of a little more than 10^8. It is evident, then, that a multiplier with a conventional anode system would not be satisfactory for use at a gain of 10^9.

It is noticed that, in spite of the fact that the multiplier was space-charge limited, the gain continues to rise beyond the point of space-charge limitation if the voltage per stage is increased as shown in Fig. 7.

This figure shows two pulses of the same form but different amplitudes.

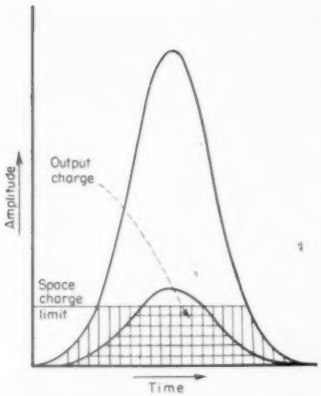

FIG. 7. Space-charge saturation for pulses of two different amplitudes

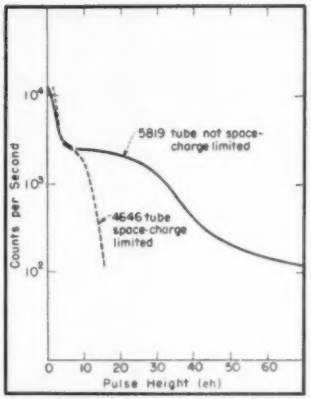

FIG. 8. Effect of space-charge limiting on a pulse-height distribution curve

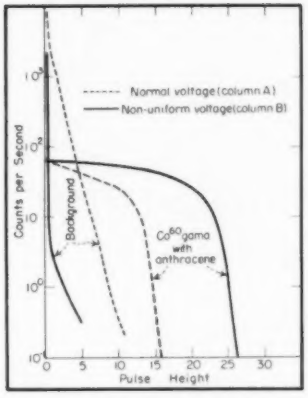

FIG. 9. Effect of excessive gain on type 4646 pulse-height distribution curves

The maximum space-charge-limited current that can be drawn is indicated. Even though the peaks of both pulses are higher than the space-charge limit, the larger one contributes more charge to the output current than the smaller one because more of the ends of the pulse get through. For this reason, the curve of gain vs voltage continues to increase with voltage even after space-charge limitation sets in—increasing, of course, at a slower rate than before. The change of space-charge limit with voltage is only a second-order effect, proportional to $V^{3/2}$.

At a gain of about 10^{10}, even the type 4646 with an output current of 0.3 ampere space-charge limits on a single electron. It is interesting to note that in this tube space-charge limit does not occur at the last, or even next to the last, dynode. Actually, the 14th dynode is the stage which first limits the output current.

Overlapping pulses. So far, the discussion has been limited to the case where electrons are emitted one at a time from the photocathode with enough separation between them so that there is no overlapping of pulses. Where practical pulse-height measurements are involved, this is by no means necessarily the case. It is possible for the components of pulses which were due to single electrons to overlap. The duration of the pulse produced by a single electron may be estimated from a gain curve, such as that shown in Fig. 6, together with the knowledge of the number of electrons per second leaving the photocathode. The duration has been found to lie between 2 and 5×10^{-9} sec. If a scintillation with a duration slightly more than an order of magnitude longer causes the release of 20 or so electrons, there will obviously be serious overlapping of the current pulses. This means that, where limited by space charge, the multiplier output will be a true representation of the pulse height for small pulses but not for large pulses.

The effect is clearly in evidence in Fig. 8. Here, using a thallium-activated sodium iodide crystal, an integrated pulse-height distribution curve for indium-114 gamma rays is given. The solid curve shows the pulse-height distribution as measured with a 5819, operated under conditions where there is no space-charge limiting. The dotted curve shows a similar pulse-height distribution taken with a high-gain tube having a conventional anode. It will be seen that the dotted curve starts to fall below the solid curve at pulse heights corresponding to the release of about 7 electrons from the photocathode. When this same curve is measured with the type 4646 multiplier, incorporating the anode structures which were previously discussed, the pulse-height distribution again resembles that shown in the solid curve.

Example of Nonuniform Voltage

Dynode	*High-gain voltage*	*Corrected distribution voltage*
PC	−2,350	−2,540
1	−2,150	−2,320
2	−2,050	−2,210
3	−1,950	−2,100
4	−1,850	−2,040
5	−1,750	−1,980
6	−1,650	−1,920
7	−1,550	−1,860
8	−1,450	−1,800
9	−1,350	−1,690
10	−1,250	−1,580
11	−1,150	−1,470
12	−1,025	−1,360
13	− 875	−1,220
14	− 700	−1,020
15	− 500	− 780
16	− 300	− 550
Collector	0	0

When a type 4646 tube is used for making a pulse-height distribution curve such as shown, the tube voltages should be set so that the over-all gain of the tube is between 10^7 and 10^9. This is accomplished by a nonuniform voltage distribution over the 16 stages, retaining large voltage steps in the region of the photocathode and first dynode and at the final dynodes and anode. An illustrative example of this type of voltage distribution is seen in the table. Figure 9 shows a typical pulse-height distribution for Co^{60} and an anthracene crystal made with a Type 4646 multiplier.

* * *

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High-Energy Particles and the Scintillation Counter

LIQUID PHOSPHOR CONTAINER consists of recessed rectangular metal outer frame with thin foil windows cemented in with Araldite cement that does not contaminate phosphor. Where container joins photomultiplier magnetic shield, a glass window is cemented into another recess. Typical counter telescope consists of three or four units mounted one behind the other

Particle scattering and meson experiments carried out with G-M and proportional counters involve long counting times if accuracy is to be obtained. The scintillation counters shown here, coupled with high-speed electronic circuits, can be used to collect more accurate data in much less time

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APPLICATION of the scintillation counter to the detection of high-energy particles is typified by the techniques and apparatus developed at the Radiation Laboratory in Berkeley. Here there is available a variety of particle accelerators permitting experimental work with almost every fundamental particle over a wide energy range. The organization of the research follows two complementary lines of investigation:

Particle scattering experiments. Elastic and inelastic interactions between the so-called "classical" nuclear particles are measured:

1. Attenuation measurement of absorption and total cross sections.

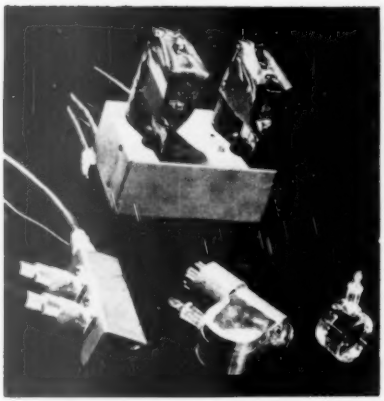
2. Measurement of scattered flux intensity as a function of scattering angle over a wide range of incident and final energies for various target materials.

Meson experiments. The interactions of the quantized "pieces" of nuclear field with the stable nuclear species are measured:

1. Measurement of production cross sections as a function of Z, incident and final particle type and energy.

2. Measurement of interaction cross sections—in principle similar to the scattering experiments, but in practice greatly modified by considerations of low intensity, poor detection efficiency, broad energy distribution, and so forth.

These lines of pursuit correspond roughly to the exploration of the nuclear field in the bound state on the one hand, and in the unbound state



TWIN COINCIDENCE UNIT uses liquid phosphor contained in flat-ended cylindrical glass bottles. Complete unit, shielded from extraneous light by black paper and tape, is shown at top. Components—chassis, photomultiplier with phosphor container, and container alone—are shown below

SMALL STILBENE CRYSTALS are mounted on flat surfaces of aluminum light "conductors" leading to photomultipliers in this counter telescope. Arrow shows particle path through four counters, range and differential range absorbers. Triple coincidence train counts all particles above critical energy set by range absorber. Quadruple train counts all those above a somewhat higher critical energy, set by differential range absorber

on the other. Much intermediate and corollary research is also pursued.

This division of high-energy research also exhibits itself in the distinctive methods of experimental treatment developed in each case. Particle scattering experiments employ directional coincidence counter telescope units, frequently using supplementary devices for extracting additional information about the particles, such as range or differential range absorbers. From the standpoint of instrumentation, the application to meson investigations followed as a natural consequence of the rapid refinement of the tool for scattering experiments. At this laboratory, the very specific decay properties of mesons are used to identify them amidst a veritable welter of accompanying radiation. Such techniques exemplify the class of apparatus which makes use of properties intrinsic to a particle, as contrasted to the class of instrument which measures kinematic properties.

The most conspicuous research is being performed using machines whose outstanding feature (as far as concerns counting problems) is the pulsed nature of their radiation output. These radiation fluxes have instantaneously very high intensities and are frequently surrounded by a high random particle background.

In a typical proton scattering experiment, the collimated incident beam from the 184-inch f-m cyclotron consists of about 10^7 protons of 340 Mev, emerging during 25 microseconds repeated about 60 times per second. The scattered flux is measured by detectors of small aperture and so may amount to a dozen true counts per second. But these scattered protons are accompanied by a random particle flux of perhaps a hundred times that number. This consists of deuterons, protons, neutrons, high-energy electrons, some mesons and some gamma rays—all resulting from inelastic interactions in the surrounding matter. The energy distribution of this background ranges up to 340 Mev, of course, but is mostly concentrated at a few Mev. Somewhat similar background problems are encountered in research work in which the 300-Mev electron synchrotron is employed.

Prior Counting Technique

Until 1948, the principal type of detector available for high-energy nuclear research was the proportional gas counter; consider its behavior in such an experimental situation. The "background" particles of a few Mev will lose most of their energy in the counter gas; the elastically scattered high-energy protons will lose of the order of hundreds of kev. Hence the undesired background pulses are generally larger than the pulses we wish to count, and are in the relative abundance of 100:1.

To make matters worse, the average proportional counter has a rise time of a few microseconds, and a simple statistical argument shows that the permissible counting rate to avoid pile-up and blocking is then very low, perhaps a few true counts per minute. (With continual, careful servicing, proportional counters will operate with much shorter effective rise times, but this imposes much too severe a restriction in multicounter experiments.)

In the face of what is essentially a problem of adverse signal-to-noise ratio, the only solution is to employ triple and quadruple coincidence telescopes operated at very low coincidence rates and to use absorbers to discriminate against low-energy particles. The technique has been well described, notably by Kelly, Hadley, Leith, Segrè, Wiegand and York. Their classic *n-p* scattering experiment (*1*) required several months of operating time; using scintillation counters, data of much higher accuracy is now obtainable in a matter of days.

The Scintillation Counter

It is indeed already obvious why such an improvement is obtainable using scintillation counters: As in other fields of application, the signal-to-

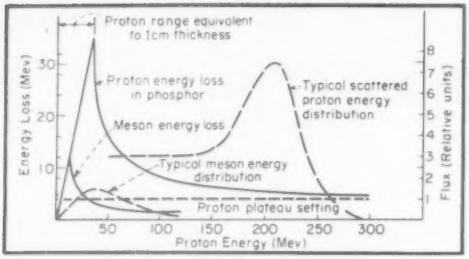


FIG. 1. Behavior of fast particles in an "average" organic phosphor. [Approximately $(CH)_n$, $\rho = 1.25$]

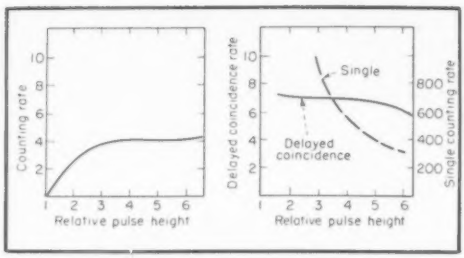


FIG. 2. Typical proton plateau for a single counter (a, left), and a meson plateau (b, right)

noise ratio is improved many fold, because of superior resolving time and improved relative pulse heights.

Since the scintillation phosphor is dense, the energy abstracted from a penetrating particle can be substantially increased, so that the corresponding pulse competes at least on a par with most of the background, as will be shown. Coupled with this is the reduction in resolving time by several orders of magnitude, due to the very rapid response of photomultipliers and the fast decay time of the prominent organic phosphors. Consequently, most simple scattering experiments are now performed using twin coincidence telescopes; in particular experiments, it is even possible to use single counters.

Of course, scintillation counters have many other comparably desirable properties which we can only enumerate: ruggedness, reproducibility, stability, flexibility of geometry, excellent electrical signal-to-noise ratio, and so forth.

There do exist experimental situations in which the scintillation counter is not necessarily the most advantageous detecting instrument, however. This is true whenever the background flux consists of predominantly nonionizing radiation and the detected particle is a heavily ionizing one (there being no stringent resolving time criterion). This is because the dense phosphor makes a relatively good converter. Under such conditions, the proportional gas counter is still superior. Certain electron synchrotron and betatron experiments, with a high gamma-ray and neutron background, fall in this category.

High-Energy Response

How will an ordinary laboratory scintillation counter behave in a high-energy particle flux? Figure 1 summarizes the expected pulse-height distribution as a function of energy for protons and mesons passing through a 1-cm-thick organic phosphor. It assumes proportionality between energy loss and luminescent intensity; this is a satisfactory qualitative assumption for penetrating particles.

Note that with sufficient gain and appropriate discriminator setting ("proton plateau"), the counter can be made to detect protons ranging from about 5 Mev to over 350 Mev. For higher discriminator settings, the detected energy range is cut back at both ends, and at the highest pulse setting, the system just detects particles of crystal-thickness range. With the proton energy distributions commonly encountered, such a sensitivity curve results in a plateau characteristic as illustrated in Fig. 2*a*.

Analogous meson curves are plotted on the same scale in Fig. 1 to exhibit the much smaller pulse heights associated with these particles, because of their lower rate of ionization. Thus, in a typical experimental situation in which many protons appear for each meson, a very broad pulse-height spectrum obtains, in which there is little hope of observing a plateau for mesons. However, if the delayed coincidences between meson decay products are used as the criterion for pulse selection, then meson plateaus are indeed observed. These situations are illustrated in Fig. 2*b*.

High-Energy Counters

Nearly all applications of the scintillation technique to high-energy research involve the use of several units in one or more coincidence telescopes—in scattering investigation for the purpose of defining particle energy and direction, in meson research to aid in identifying the decay events and products as such. Consequently certain geometric restrictions which do not arise in the low-energy region are imposed on the counter units:

1. Phosphor volumes of large area and relatively thin, uniform thickness must be used, so that the particles can penetrate through the telescope.

2. Uniform material density must exist along any coincidence line, so that the telescope's sensitivity is the same over its counting area. This requires that the fluorescence be observed from one of the thin edges of the phosphor volume.

3. Telescopes should not require an unreasonable volume of space, despite the magnetic shields usually necessitated by stray magnetic fields.

For these reasons, 1P21 and 1P28 photomultipliers are used predominantly in the equipment. Some work has been done using light pipes and 5819 tubes, but only in situations in which the phosphors must unavoidably be located in high magnetic fields.

Counter units illustrating these principles are shown at the beginning of this article. To complete this survey of counter geometries, Fig. 3 depicts a typical arrangement employed in meson research. It is seen that these various counter systems have much in common.

Electronics for the Problem

Actually, it is only comparatively recently that mechanical refinement of the scintillation counter has received such attention. The tremendous improvement in, effectively, detection signal-to-noise ratio meant that, to exploit these detectors fully, most of the earlier efforts were applied to electronic refinements. Just as with other particle counting tools, what we

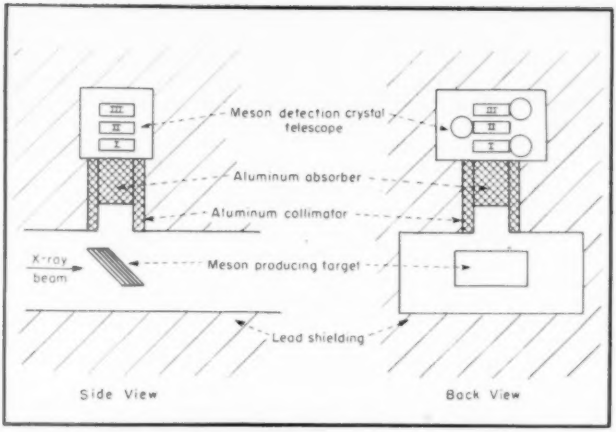


FIG. 3. Typical meson detection telescope

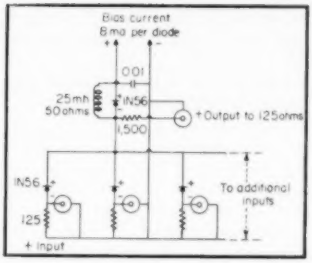


FIG. 4. Biased-diode coincidence mixer

wish to do is to amplify and shape the signal pulses, mix them in coincidence circuits and finally record them. It is desirable to do this at the very much higher speed permitted by these detectors and sometimes over a much wider dynamic range than was hitherto necessary.

In the conventional apparatus, the photomultiplier output pulses are fed through coaxial lines to pulse amplifiers. (The cathode follower employed "in the early days" at the photomultiplier is superfluous. Frequently the system would continue to perform almost equally well with the cathode follower filament cold, simply because for such steep pulses, almost as much signal current feeds through the grid capacitance as is generated by the cathode follower.) As far as amplification is concerned, three types of units have been found desirable: linear amplifiers of 10-Mc bandwidth with maximum gain of 500; pulse generating amplifiers with 20- to 50-mv trigger level, producing 40-volt rectangular pulses, 0.2 μsec wide; distributed amplifiers of 200-Mc bandwidth with a gain of 10, usually cascaded.

In applications involving the identification of small pulses in a sea of large ones, it is necessary to limit and clip pulses. One scheme employs zero-biased 6AH6 pentodes driven to cut-off using shorted-stub line clippers across the plate load. A simpler limiting scheme employs 1N56 diodes and is somewhat similar to conventional automatic noise-limiting circuits.

Much attention has been given to coincidence circuits; several more-or-less orthodox vacuum-tube circuits are in use, such as a modified Rossi pentode mixer, and a 6BN6 mixer. Wiegand has developed the distributed line twin coincidence mixer (*3*) for certain special applications discussed later.

With the advent of high-output photomultipliers and sharp cut-off germanium diodes, the trend is towards systems having few, if any, vacuum tubes between photomultipliers and scalers. The rather orthodox crystal mixer circuit shown in Fig. 4 has been used in various forms for high-level multiple coincidence work. It has a resolution time of about 10^{-8} sec.

Figure 5 illustrates the Neher crystal-diode bridge coincidence mixer in two forms. It has an ultimate resolving time of somewhat less than 10^{-9} sec and is used in a time-of-flight measuring system; about 30% energy resolution for 100-Mev protons has been observed. The alternate version, useful when coincidence can be per-

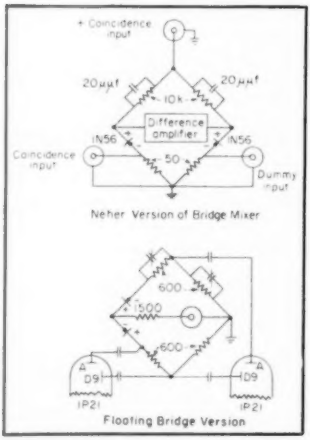


FIG. 5. Bridge coincidence circuits

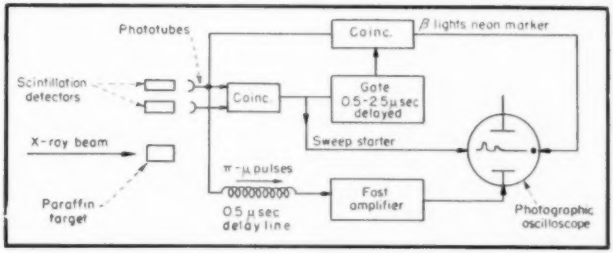


FIG. 6. Typical π-μ-β decay detecting system

formed in the immediate proximity of both signal sources, eliminates the difference amplifier, but requires floating both sides of the photomultiplier signal circuits.

Many elaborate schemes are being employed for interpreting the shaped and mixed signals; those developed for handling meson pulses are representative. Alvarez' early experiments required identification by means of the μ-β decay process; in his equipment, coincidences between initiating and delayed pulses were recorded in a series of channels of time width and separation of 2 μsec. This scheme has been elegantly developed by Steinberger and Steller.

The ultimate in resolution time is demanded of systems employed for identifying the π-μ-β decay chain. Wiegand and Chamberlain originally employed a photo-oscillographic recording method shown in Fig. 6, together with visual scanning for final interpretation. In this scheme, the scope sweep is triggered by a particle causing a coincidence between counters, which also starts a delayed gate. If a β appears during that gate, a neon marker is lit, which also records on the film. Meanwhile the train of pulses succeeding the coincidence has been held up in the delay line to give the sweep time to start. A continuous film strip recording is made, and only those traces are eventually measured which show two consecutive pulses together with a neon pulse.

Jakobson has recently developed a system in which scaler recording is employed exclusively. For the equipment to occupy a finite amount of space, only a portion of the information available at any one time can be analyzed. Figure 7 illustrates the most interesting electronic components of this system, including two forms of the distributed mixer, as well as a fast gate-pulse generator.

Future Development

The more interesting instrumental problems have been outlined here to indicate the degree of complexity now required. The evidence supports the contention that more exacting requirements, both in terms of accuracy and of efficiency, will be placed on instrument design in the future. Also, to make most economic use of the very expensive modern tools of nuclear physics, many techniques and devices

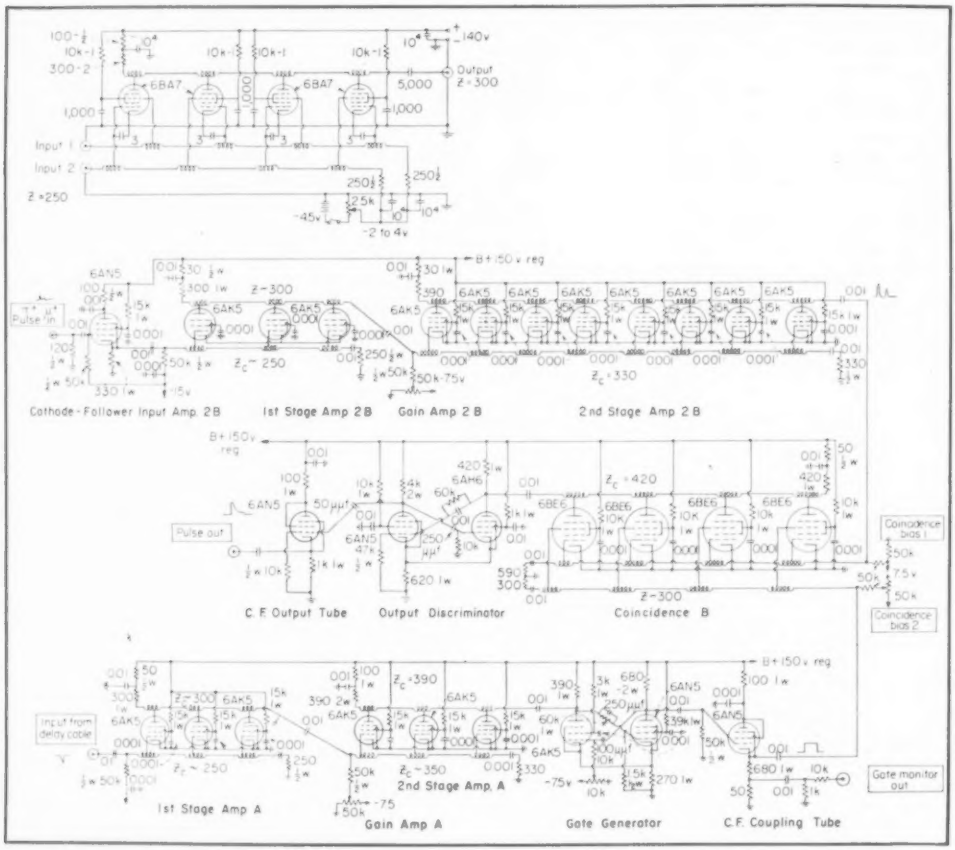


FIG. 7. Typical high-speed distributed electronic circuits for analyzing pulse presentations

developed in the computer laboratory shall be needed to facilitate the interpretational phases of experimental research.

Future instrumental development would then appear to be profitable in the following directions:

Simpler and "faster" circuit design. Using present components, the field of circuit design has been rather well exploited; new and better components are needed:

1. Photomultipliers must deliver much larger output pulses, requiring a design having a space-charge-limited current output of the order of 1 amp. The new RCA 4646 is almost halfway there, and the ultimate design is expected to deliver that peak current.

2. Photocathodes should be developed having a higher photoconversion efficiency. At present this averages 6–7%. It is the only remaining major weakness wherein an order of magnitude in speed and pulse definition might be gained.

3. Transistors should be applied to the problems of pulse counting; units of commercial reliability and quantity must be made available on the same basis as modern vacuum tubes. High-output photomultipliers will permit virtual elimination of tubes between counter and scaler; transistors would eliminate most of the remaining vacuum tubes in a representative scaling system. The consequent simplification of servicing and power-supply requirements would permit substantial expansion of signal-handling facilities.

Proportional energy-pulse techniques. These are being developed to make more efficient physical use of experimental set-ups, especially in the medium-high energy range (50–500 Mev). Fragmentary experimental and theoretical evidence indicates that fast organic phosphors show good linearity for penetrating particles above 5 to 10 Mev. Several problems, among others, arise:

1. Because of geometric limitations already outlined, 40% variations in sensitivity are observed across phosphor containers.

2. Wide dynamic range is required in the interpreting equipment, as indicated by the arguments summarized for Fig. 1.

3. Pulse height vs energy relation is double-valued (see Fig. 1); even though selection methods can be applied for discriminating against one side or the other, the problem becomes complicated in a flux in which other energetic particles are present, such as deuterons and tritons.

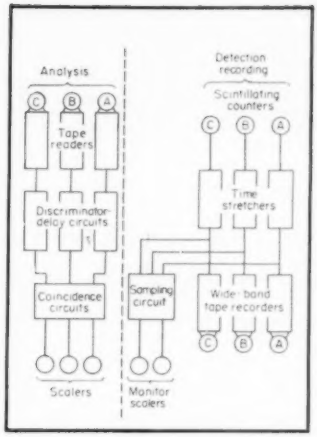


FIG. 8. Proposed pulse analysis-recording information system ("PARIS")

Information recording and interpreting systems. Present electronic equipment has a tendency to expand in spatial dimensions to provide greater counting efficiency. The time dimension has been overlooked; these accelerators have dead times of the order of hundreds of times longer than the active periods. It would seem advantageous to write the counter information in some form of storage device during the active time and perform a leisurely analysis during the dead time.

Furthermore, after the initial "setting-up" tests are completed, the subsequent experimental information might be semi-permanently recorded so that the experiment could then be "re-run," so to speak, at the investigator's will. Such schemes may become of importance in connection with very large machines, such as proton synchrotrons; investigations using these accelerators will be expensive and means must be sought to increase the utility of an experimental period.

To exemplify the type of information system which might fulfill these conditions, consider a proposed application to the more conventional π-μ-β triple delayed coincidence-anticoincidence telescope counter arrangement, as displayed in Fig. 8. The pulse data from each of the three detectors would be stored during the active time in a corresponding "time-stretcher," for instance, graphecon tube screens. During the intervening dead time, the screens would be scanned more slowly and the stretched pulses would be recorded on three tapes together with appropriate fiduciary time markers. The three tapes could then be examined later in reading equipment located elsewhere; the pulses might be mixed with successively different discrimination levels, delay and gating times, and so forth, so that the maximum information could be extracted from a given accelerator operating period for a given experimental set-up. During the course of the actual experiment, a representative portion of the information should be monitored, of course, to assure proper operation.

Aside from the economic aspects of such a technique, several experimental advantages would obtain. First, the ability to re-scan an experiment would be an invaluable aid in checking on its consistent performance as well as often yielding valuable clues concerning improvements of future set-ups. Second, information concerning comparative pulse heights and decay times would be obtained at a uniform level for all pulses and with random time mixing. Third, it would become possible to compare associated experiments with a "scanning objectiveness" not otherwise possible. Finally, in the presentation of crucial experimental results, such a record would constitute the most objective possible data.

It is thus seen that scintillation counters are making possible a great extension and refinement of the types of investigation associated with high-energy accelerators. Almost equally as important as this, is the increased volume of consequential problems which can be undertaken for graduate training with a given machine. Indeed, it is appropriate to credit the developments recorded here to the several groups under the guidance of Professors McMillan, Moyer, Segrè and Thornton at Berkeley. This paper is essentially a summary of their work.

* * *

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Neutron-Detecting Phosphors

Testing of over 300 phosphor samples has led to the development of a variety of scintillators containing lithium. Previous experimental work and suggested methods for producing neutron-induced luminescence are reviewed

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DURING THE DEVELOPMENT of the scintillation counter and its applications to the measurement of gamma radiation and charged particles, it had been anticipated that these techniques might be used to provide a new means for the counting and energy measurement of neutrons (*1, 2*).

As an example, slow neutrons may be detected with a crystal scintillator of tin- or thallium-activated lithium iodide (*3, 4, 5*). Such a crystal, preferably prepared from lithium enriched in the Li^6 isotope, would prove to have many advantages as a slow-neutron counter over the conventional BF_3 gas proportional counter.

In regard to one advantage in particular, the lithium iodide scintillation counter might replace the long BF_3 counter generally used in neutron diffraction apparatus, where the much smaller sensitive volume of the crystal would bring about a great reduction in shielding needed to minimize the effect of stray radiation.

Possible detecting methods. The salient properties of neutron-detecting phosphors, such as high counting rates, high detection efficiencies, and geometric flexibility, suggest many new applications and new experiments.

An application not directly related to the scintillation counter is the visual or photographic observation of a neutron beam by means of a neutron-sensitive luminescent screen. A very promising use of a neutron-sensitive crystal scintillator is in connection with the measurement of neutron energies. It may be expected that a fast neutron which is absorbed by a Li^6 nucleus of a lithium-containing phosphor will produce a scintillation through excitation of the phosphor by the products of the $Li^6(n,\alpha)H^3$ reaction, and that the pulse height measured at the output of the photomultiplier will be proportional to the Q (4.785 Mev) of this reaction plus the energy of the absorbed neutron.

In the same way, a phosphor which contained boron would produce a scintillation resulting from the products of the $B^{10}(n,\alpha)Li^7$ reaction. This case, however, is complicated by the fact that there will be an uncertainty in the deduction of the absorbed neutron energy because of the probability that the recoil Li^7 nucleus may emerge in an excited state (*6*).

A neutron can produce a scintillation by excitation of the phosphor by charged particles resulting either from absorption of the neutron or from the production of a recoil proton. Scintillations from recoil protons were observed when Bell found that very large pulses were produced when anthracene was exposed to the fast neutrons from a Po-Be source (*7*).

Both of the isotopes, Li^6 and B^{10}, have high thermal neutron absorption cross sections. Attempts have been made to incorporate or admix either of these elements with the phosphor material. A phosphor which responded to slow neutrons was made by Hofstadter by fusing boric acid with zinc sulfide (*8*).

Liquid scintillators also have been considered as a means of detecting neutrons. Peterson has prepared some trimethyl borazol as a boron-rich solvent for terphenyl (*9, 10*). This solvent polymerizes rapidly even when diluted with an equal amount of xylene. Polymerization is retarded considerably if the solution is made of 10% borazol and 90% xylene. A small amount of terphenyl was added to all of these solutions and tested with γ-rays and α-particles. It was found that there is little if any quenching of the luminescence, but as is generally true for liquid scintillators, the ratio of the excitation efficiency of α-particles to γ-rays is very small. Because of this fact, such a neutron scintillation counter may be expected to be of little general use in the presence of a strong γ-ray background.

Taking advantage of the polymerization of the borazol, a paste was made of it and zinc sulfide. The paste was allowed to stand and harden, then crushed into a white powder. With the resulting high-boron-content-phosphor, it was possible to obtain a slow-neutron counting yield of 15–20%.

Taking into consideration the schemes which have been described,

together with many possible variations and refinements, it appears that an ideal neutron-detecting phosphor would be very nearly realized as an optically clear single crystal of a lithium-containing compound having high luminescent efficiency, a short decay time, and a high concentration of lithium. It would be desirable that this compound be chemically stable and have a low γ-ray and a low competing neutron absorption cross section.

Although LiI, activated with either thallium or tin, has a high lithium content and a decay time constant of less than a microsecond, its luminescent efficiency is only about 4% that of NaI(Tl) and it has undesirable characteristics with regard to the other requirements. The presence of iodine gives a relatively high γ-ray cross section and a high competing absorption cross section for fast neutrons.

Work at ORNL

Clear single crystals of thallium- and tin-activated LiI have been grown at this laboratory only after carefully controlled and thorough vacuum and heat dehydration of the purified hydrate. Water and oxygen in the Pyrex or quartz crystal-growing crucible containing the anhydrous material must be completely removed before the crucible is sealed off. Crystals of LiI are deliquescent and more chemically unstable in the presence of moist air than NaI. In the presence of the slightest trace of water and oxygen, LiI undergoes hydrolysis and oxidation, resulting in the liberation of free iodine thereby giving the crystal a brown discoloration. Nevertheless, it has been found that a crystal may be kept in good condition indefinitely in a dry, well sealed container.

In connection with the work being done at ORNL in an attempt to find different neutron-sensitive phosphors, over 300 potential phosphor samples were prepared and tested. A large group of these samples consisted of compounds containing both lithium and oxygen, namely: the lithium silicates, titanates, zirconates, stannates, phosphates and tungstates. These samples were prepared in microcrystalline form by the dry reaction at an elevated temperature of the component oxides, acids, or carbonates, plus an activator.

In preparing the phosphors, lithium was used in the form of the carbonate which was precipitated by distilled ammonium carbonate from purified lithium chloride. The lithium carbonate obtained in this way was of a high degree of purity and was used exclusively for all the lithium phosphor preparations. The other component compounds used were tested and considered sufficiently free of impurities to start with.

The finished phosphor powders were examined with both 3,650Å and 2,537Å ultraviolet light from a filtered mercury vapor lamp. They were tested for their response to alpha particles by spreading a thin layer of the phosphor powder on a micro cover glass which was then supported between a polonium alpha source and the photocathode of an RCA C7140 photomultiplier.

Experimental results. The table shows the results obtained with phosphors which responded with an appreciable degree of luminescence. No tabulation is given for excitation by neutrons since the energy of the polonium alphas (5.3 Mev) is near enough to that expected from the absorption of neutrons by Li^6. This fact was confirmed at times during the tests using a moderated Po-Be source. A special test with neutrons was made with $Li_2Si_2O_5(Ti)$, a quarter-inch thick translucent slab of which was obtained by slowly cooling the melt. This slab gave a thermal neutron counting efficiency of 40%.

Although $Li_2Si_2O_5(Ti)$ is an efficient phosphor, its relatively long decay time (200 μsec) is a disadvantage, and consequently an effort was made to find an oxide phosphor having a shorter decay time. Cerium-activated Li_2CaSiO_4 has the shortest decay of those prepared, and responds very strongly to ultraviolet and alpha particles.

The zirconium compounds, including zirconia, generally exhibit a strong

Response of Phosphors to Ultraviolet and Alpha Particles

Phosphor			*Response*					
			Ultraviolet excitation				*Polonium-α excitation*	
	Impurity		*3,650 Å*		*2,537 Å*			
Compound	*Mole %*	*Substance*	*Intensity**	*Color†*	*Intensity**	*Color†*	*Intensity*	*Decay time constant*
Li_2SiO_3	10	Ti			M	R-W	M	200
Li_2SiO_3	3	Ta			M	W	M	200
Li_2SiO_3	4	Sn			S	B	M	200
Li_2SiO_3	1	Sb			M	B	S	200
$Li_2Si_2O_5$	5	Ti			S	Y-W	S	200
$Li_2Si_2O_5$	3	Ta			S	W	VW	100
$Li_2Si_2O_5$	4	Sn			W	V		
$Li_2Si_2O_5$	1	Sb			W	V	M	200
Li_2CaSiO_4	1	Sb			W	V	W	50
Li_2CaSiO_4	5	Ce	S	B	VS	B	M	0.2
Li_2TiO_3	1	Mn	M	R	W	R		
$Li_2Ti_2O_5$	1	Mn	M	R	W	R		
Li_2TiSiO_5	0				M	W		
Li_2ZrO_3	0		W	V	M	B-W	S	2
Li_2ZrO_3	0		W	V	M	B-W	S	2
$Li_2Zr_2O_5$	0		W	V	M	B-W	S	2
Li_2ZrSiO_5	0		VW	W	S	W	M	100
Li_2ZrTiO_5	0		M	W	S	W	S	4
Li_2CaZrO_4	0				M	V		
Li_2CaZrO_4	1	Pb			M	R-V		
ZrO_2	0		W	V	S	W	M	2
$CaWO_4$	0				VS	B	S	10
Li_2WO_4	0				M	W		
Li_2WO_4	1	Pb			W	W		
Li_2SnO_3	1	Ti			VS	B	S	10

*VS, very strong; S, strong; M, Medium; W, weak; VW, very weak
† R, red; Y, yellow; B, blue; V, violet; W, white

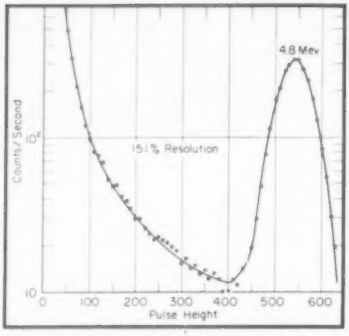

FIG. 1. Pulse-height spectrum obtained by irradiation of LiI-SnI_2 crystal with slow neutrons

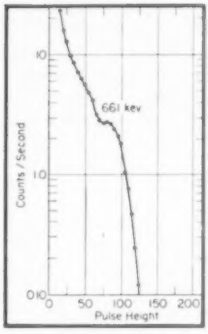

FIG. 2. Pulse-height spectrum of LiI-SnI_2 obtained by irradiation with Cs^{137} γ rays

emission under ultraviolet and alpha-particle excitation, and do not require the incorporation of an activator impurity. The decay times are short enough for most applications involving neutron detection. It has been found, however, that the melting point of these zirconates is too high for growing large crystals from the melt with a conventional furnace, although crystals of sufficiently large size might be made by the Verneuil method.

Li_2SnO_3, activated with one mol per cent of TiO_2, proved to be an efficient phosphor. The concentration of titanium could be varied over a range of ten to one without much change in the luminescence. The efficiency, emission spectrum, and decay time were found to be much the same as Ca_2WO_4. The Li_2SnO_3 was prepared by a dry reaction of equimolar proportions of Li_2CO_3 and SnO_2 for several hours at a temperature of 1,100° C in an air atmosphere. This compound was not found to be reported in the literature, so that to prove its existence, an X-ray diffraction pattern was taken of a powdered sample.* The pattern gave evidence of a definite structure and showed only a small trace of unreacted SnO_2 and no lines corresponding to either Li_2O or Li_2O_2. The comparatively simple diffraction spectrum signified the presence of only a single phase.

Attempts to make large single crystals of these oxide phosphors by slow cooling of the melt did not meet with much success. They are either unstable at high temperatures, have excessively high melting points, or have incongruent melting points. Complications of crystal growth must be taken care of which do not obtain in the case of the simply grown alkali halides. On this account, the lithium halides with various activators have been prepared and tested.

In the course of testing the effect of various activators in LiI, it was found that strong luminescence occurs under ultraviolet excitation when LiI is activated with tin. To determine its response to slow neutrons, crystals of this phosphor containing about 0.1 mol per cent of SnI_2 were grown from the melt. One of these crystals was selected which was about $1 \times 0.5 \times 0.5$ cm in size, irregular in shape, transparent, and ranging in color from faint yellow to nearly colorless. It was ground smooth on one side and optically connected to a 5819 photomultiplier. The crystal was exposed to uncollimated neutrons from an unshielded Po-Be source. A flux of slow neutrons was obtained by placing a block of paraffin behind the source. The measured pulse-height spectrum is shown in Fig. 1. Even in the presence of the γ-rays and fast neutrons emanating from the source, and in spite of the irregularity and non-uniformity of the crystal, the pulse-height spectrum exhibits a resolution of 15% for the monoenergetic excitation of the phosphor from the reaction of the moderated neutrons with Li^6.

Figure 2 shows the pulse-height spectrum of the same crystal and mounting showing the peak due to photoelectrons from Cs^{137} γ radiation. A similar spectrum was taken after replacing the LiI-SnI_2 with a NaI-Tl crystal. A comparison of the pulse heights at the photoelectric peaks gives an electron excitation efficiency for LiI-SnI_2 relative to NaI-Tl of 1/24.5. A comparison of the pulse heights obtained from LiI-SnI_2 for Cs^{137} gamma rays and for neutrons, assuming linearity, gives a Q of 4.5 Mev for the $Li^6(n,\alpha)H^3$ reaction which is 94% of the correct value. The scintillations produced by neutrons on LiI-SnI_2 were observed on an oscilloscope, and the decay of luminescence appeared to be exponential with a time constant of about 0.7 μsec.

In addition to the results obtained with LiI, it was found that tin will activate LiBr. One tenth mol per cent $SnBr_2$ was mixed with LiBr and a one-inch-diameter single crystal grown in a quartz crucible. The crystal was perfectly colorless and transparent. A pulse-height spectrum for thermal neutrons was taken in the same way as for LiI(Sn) and the resolution was found to be 27%. The scintillations were displayed on an oscilloscope, and the decay time constant was found to be approximately 1.5 μsec.

The development of neutron-sensitive phosphors has reached the point where they will begin to find an increasing application in neutron measurements. A search will continue for scintillators which will have better chemical, nuclear, and luminescent properties.

* * *

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Low-Level Counting Techniques

With the same statistical error, counting time was reduced by a factor of three using pulse-height discrimination with a $C^{14}O_2$ -filled proportional counter. Equations relating sample-to-background ratios to statistical error are derived

By ARTHUR J. FREEDMAN*
and ERNEST C. ANDERSON†

THE PROBLEM of counting samples of low specific activity is often encountered in biological tracer work and in long-lived natural radioactivity investigations.

The precision of the determination of a weak activity can be increased by two methods. One is by the use of larger detectors and larger samples, thus increasing both the sample and background counting rates; the other involves reducing both rates (e.g., smaller detectors and samples or pulse-height discrimination techniques) in such a manner as to improve the sample-to-background ratio.

Loevinger and Berman (*1*) discuss the problems of comparing counters and of determining the most efficient operating conditions for a given counter. However, they do not present the specific equation relating limiting background and sample ratios as an explicit function of sample strength.

Theory

The relation between changes in sample and background rates and the resultant change in statistical accuracy of the net sample count may be derived in the following way.

Let S and B represent the net sample-counting rate and the background rate, respectively. Assume that an equal time will be spent counting sample and background. This is the most efficient arrangement only when the net sample rate is small compared to the background rate. It is used to simplify the mathematical analysis and can be shown to introduce no significant error. The same counting time is used in the two counting methods to be investigated since it is desired to compare the methods in terms of statistical accuracy obtainable in a given time.

The fractional error in the net sample rate, if statistical fluctuations are the sole source of error, is

$$\sigma_s/S = [(S + B)t + Bt]^{1/2}/St \quad (1)$$

where σ_s is the standard deviation and t is the counting time. In order that an improvement shall have resulted, it is necessary that σ_{s_2}/S_2 be less than σ_{s_1}/S_1, where the subscripts 1 and 2 refer to the respective counting methods. This may be expressed as

$$\frac{(\sigma_{s_2}/S_2)^2}{(\sigma_{s_1}/S_1)^2} < 1 \quad (2)$$

Combining Eqs. 1 and 2

$$\frac{S_2}{S_1} > \left(1 + 2\frac{B_2}{S_2}\right) \Big/ \left(1 + 2\frac{B_1}{S_1}\right) \quad (3)$$

so that

$$\frac{B_2}{B_1} < \frac{(S_2/S_1)^2(1 + 2B_1/S_1) - (S_2/S_1)}{2B_1/S_1} \quad (4)$$

if improvement has been obtained.

Equation 4 is represented in Fig. 1 for the case in which the second counting method has a higher counting efficiency or uses larger samples than the first but also gives a higher background. The family of curves for several values of S_1/B_1 are given.

In the limiting case that $S_1/B_1 = 0$, Eq. 4 reduces to $B_2/B_1 < (S_2/S_1)^2$. The background can therefore increase as rapidly as the square of the sample

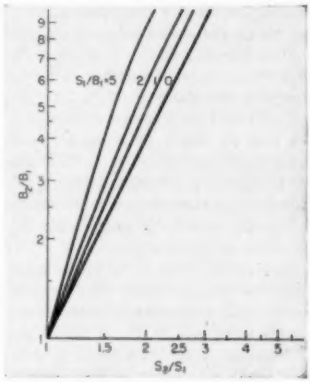

FIG. 1. Maximum permissible background increase vs sample increase

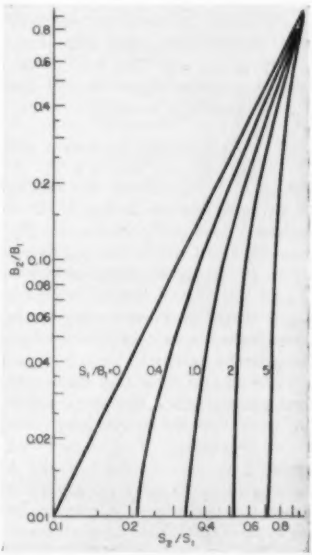

FIG. 2. Minimum essential background decrease vs sample decrease

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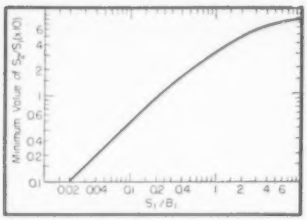

FIG. 3. Minimum permissible ratio of sample counts (S_2/S_1) as a function of initial sample-to-background ratio (S_1/B_1)

increase even in this worst case without decreasing the statistical accuracy for a given counting time. If $S_1/B_1 > 0$, an even more rapid increase in background is permissible.

Figure 2 is the analogous graph for the case in which both sample and background are reduced. In this case the background reduction factor must exceed the square of the sample reduction factor in order to compensate for the lower counting rates.

To a given value of the initial sample-to-background ratio, S_1/B_1, there corresponds a minimum value of the sample reduction, S_2/S_1, at which the background must be reduced to zero in order to maintain the initial statistical accuracy without increasing the counting time. Reduction of the net sample count below this point would clearly result in diminished accuracy even though background were completely eliminated. The relation between the minimum permissible value of S_2/S_1 and B_1/S_1 is simply

$$S_2/S_1 = 1/(2B_1/S_1 + 1) \qquad (5)$$

Equation 5 is derived by setting B_2/B_1 equal to zero in Eq. 4. It is presented graphically in Fig. 3. By consulting this graph, one can determine for a given sample-to-background ratio S_1/B_1, the limiting minimum value below which the net sample count cannot be reduced in an attempt to reduce background.

These results show that great care must be exercised in choosing a counting method on the basis of sample-to-background ratios. They suggest that attempts to increase the ratio by a reduction in both rates are erroneous unless the background is reduced by more than the square of the sample reduction. Conversely, if it is possible to increase the sample count by as much as the square root of the factor of background increase by using larger or more efficient detectors, an improvement in counting statistics will result even though the actual sample-to-background ratio has decreased.

It must be noted that these considerations apply only when the variations in S and B are due solely to statistical fluctuations so that $(\sigma_N)^2 = N$. If the background is not constant within these limits but varies more widely as a result of extraneous physical causes, then the above analysis does not apply and the optimum may be shifted in favor of lower values of the background.

Pulse-Height Discrimination

The basis of the pulse-height discrimination (PHD) technique for the improvement of sample-to-background ratios is that the pulse-height spectrum of the sample may be sufficiently different from the background spectrum so that it is advantageous to count pulses only in a narrow spectral region.

An obvious case is the counting of alpha particles in the presence of beta and gamma radiation. A refinement of this is the multichannel system which has proved to be such a powerful tool in the study of transuranic alpha emitters. This system makes it possible to count alpha particles of a single energy in the presence of many others of slightly differing energies.

Obviously the PHD technique is most efficient in separating one monoenergetic radiation from another or from a continuous background. We are here concerned with the more difficult problem of partially separating two continuous and overlapping spectra in the most efficient manner.

The usefulness of PHD, in conjunction with beta proportional counters, in attacking this problem was first pointed out by C. J. Borkowski (*2*). He presented data showing that the sample-to-background ratios for weak samples of C^{14} and Fe^{55} may be greatly improved by this method. A sample was counted with a proportional counter plus a discriminator set to count pulses only in a restricted pulse-height region. A sample-to-background ratio obtained for C^{14} was approximately 100 times greater than that obtained with the same sample in a G-M counter. Since the data were taken on two different types of counters, a quantitative interpretation is difficult. However, the encouraging nature of the results prompted a further investigation of the technique.

Carbon-14 was used in the present investigation because of its great importance in many low-level counting problems. In order to obtain maximum counter efficiency and minimum pulse-spectrum distortion, gas sample proportional counting was used.

Pure methane and methane-argon mixtures are the usual fillings for proportional counters. While up to 10% carbon dioxide can be added to a methane filling without destroying the counting characteristics of the gas, the

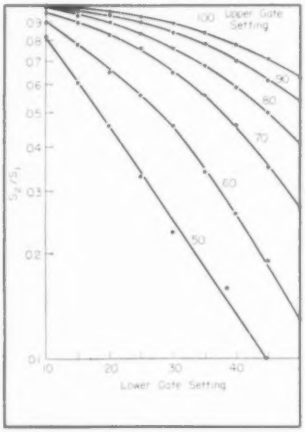

FIG. 4. Effect of pulse-height discrimination on C^{14} counting rate

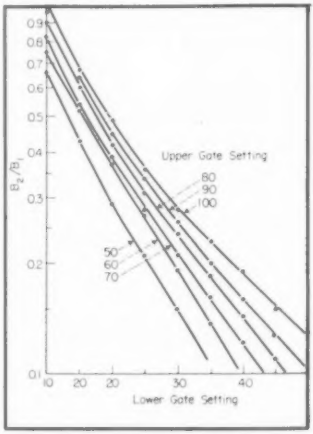

FIG. 5. Effect of pulse-height discrimination on background rate

size of sample which can be used is necessarily limited, and the counting rate is very sensitive to the composition of the filling gas. These difficulties were avoided by using pure CO_2.

Proportional plateaus obtained with pure carbon dioxide have slopes of about 10% per 100 volts compared with less than 1% per 100 volts for methane. The length and starting potential of the plateau vary in much the same way as the methane plateau but a given pressure of CO_2 requires a higher operating voltage. It should be noted that when PHD is used, the usual voltage plateau is of no significance.

Although carbon dioxide plus a quenching gas is well known for use in Geiger counters, its use alone in proportional counters does not seem to have been previously reported.

The counter tubes used were of standard brass-wall construction, 1.5 in. in diameter and 17.5 in. long. The pulses from the counter were passed through a suitable linear amplifier, then into a discriminating circuit, and finally were recorded on a scaler or a rate meter plus a chart recorder. The discriminator had both upper and lower gates, each of which could be adjusted independently.* Hence these gates could be set to cut off any desired portions of the pulse-height spectrum.

The change in sample-to-background ratio for a given $C^{14}O_2$ sample was studied as a function of discriminator settings. For various settings of the upper gate, sample and background counting rates were measured as functions of lower gate setting at counter pressures from 30 to 70 cm total pressure of CO_2 and operating voltages from 3 to 5 kv.

Results

Figures 4 and 5 show the results at 30-cm pressure and 3.4 kv. In these graphs S_2/S_1 and B_2/B_1, respectively, are plotted as functions of lower gate setting at various upper-gate settings.

In Fig. 6 the data are replotted to show B_2/B_1 as a function of S_2/S_1. Each curve corresponds to a particular maximum gate setting and varying minimum gate values.

By comparison of Fig. 6 with Fig. 2, the optimum gate settings for a given value of S_1/B_1 can be determined. (The curve for $S_1/B_1 = 0$ in Fig. 2 is shown as B in Fig. 6 for illustration.) This represents no improvement over the reference method. Points above this line correspond to a loss in statistical accuracy and points below correspond to a gain. Quantitatively, the vertical separation of the bias curves from this line represent the degree of improvement which has been obtained, and clearly, the optimum conditions, indicated by a + in Fig. 6, correspond to the point on the bias curve which is the greatest vertical distance from line B. At this point, the B_2/B_1 of the bias curve is the smallest possible fraction of the B_2/B_1 of the appropriate statistical curve. An alternative method of choosing optimum parameters is given by Loevinger and Berman (*1*).

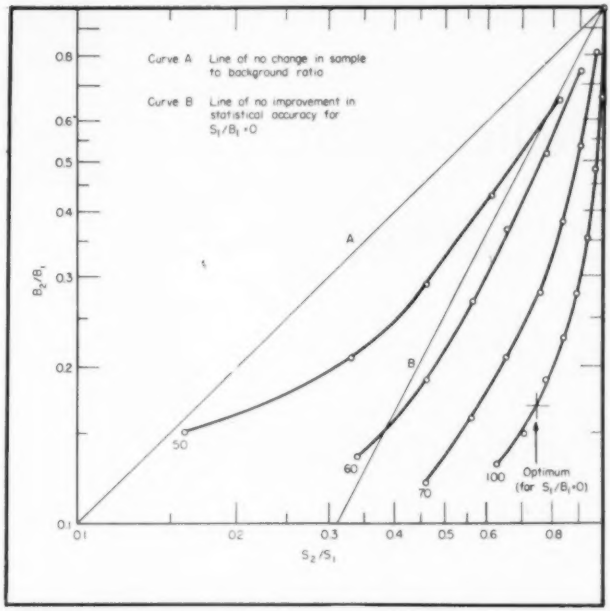

FIG. 6. Determination of optimum conditions from PHD background reduction vs sample reduction

For $S_1/B_1 = 0$, the optimum gate settings indicated on the graph (upper gate = 100, lower gate = 42) give an improved S_2/B_2 of 4.4 times S_1/B_1 (note that gate settings of 100, 50 give a better sample-to-background ratio, $S_2/B_2 = 4.8 \times S_1/B_1$, but poorer statistics in a given counting time). As a specific example, if $S_1/B_1 = 0.1$ so that $S_2/B_2 = 0.44$, the statistical fractional error in S_2 will be reduced to 0.59 σ_{s1}/S_1 for the same counting time. Alternatively, to obtain the same statistical accuracy requires that the counting time be 2.9 times longer.

For the conditions used here, the optimum upper gate setting of 100 was equivalent to no upper gate at all, i.e., all pulses greater than the lower gate setting were counted. This will not be the case in general. With tritium, one might expect the use of the upper gate to be advantageous.

The specific results reported here are applicable only to the particular detector and circuits used, but they indicate the general behavior to be expected of similar apparatus. Some improvement may be expected from a better choice of counter chamber shape, size, and pressure. A further study of these parameters and of other nuclides is planned.

* * *

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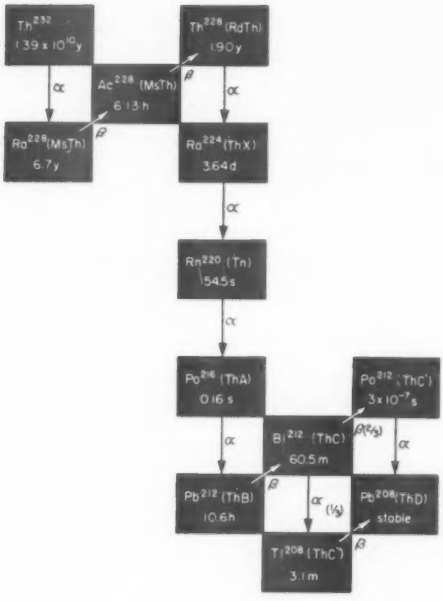
2. C. J. Borkowski, AIEE-IRE Conference on Electronic Instrumentation in Nucleonics and Medicine, October 31, 1949

* The Los Alamos differential discriminator, drawing No. 4Y-26065, and the Atomic Instrument Co. model 510 pulse height analyzer are both instruments of this type.

Radiometric Properties of the Thorium Series



Activity curves of groups in the thorium series are applied as a basis for the analysis of thorium and its daughter products by alpha and beta counting, and for the calculation of approximate beta surface dose rates

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Health and Safety Division
New York Operations Office,
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THE RELATIVELY rapid decay of the members of the thorium series following Th^{232} makes it necessary to consider the effect of time on the activity of many thorium preparations. The decays are not simple processes, as shown above. A practical method of evaluating counting results is by means of a graphical representation of the Bateman solution of the partial differential equation (*1*) for the part of the chain being measured.

With the aid of the curves, the activity of any preparation may be measured and the corresponding activity at any time in the past or the future may be calculated.

The following calculations are based on the disintegration constants shown in Table 1 (*2*). The arithmetical work has been carried out to about 1% relative accuracy, and branching decays showing less than 1% of the isotopic activity have been ignored.

Bateman Equations

The isotopes in Table 1 are each given a series number which is used as an identifying subscript in the

TABLE 1—Disintegration Constants

Series No.	*Isotope*		$\lambda(Sec^{-1})$	$T_{1/2}$
1	Th^{232}	α	1.58×10^{-18}	1.39×10^{10} *y*
2	Ra^{228}	β	3.28×10^{-9}	6.7 *y*
3	Ac^{228}	β	3.14×10^{-6}	6.13 *h*
4	Th^{228}	α	1.16×10^{-8}	1.90 *y*
5	Ra^{224}	α	2.20×10^{-6}	3.64 *d*
6	Rn^{220}	α	1.27×10^{-2}	54.5 *s*
7	Po^{216}	α	4.39	0.16 *s*
8	Pb^{212}	β	1.82×10^{-5}	10.6 *h*
9	Bi^{212}	$\frac{2}{3}\beta$, $\frac{1}{3}\alpha$	1.91×10^{-4}	60.5 *m*
10	Po^{212}	α	2.66×10^{6}	3×10^{-7} *s*
11	Tl^{208}	β	3.73×10^{-3}	3.1 *m*
12	Pb^{208}		Stable	

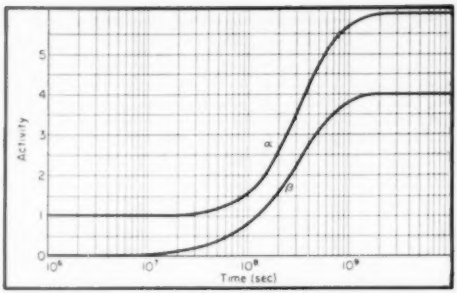

FIG. 1. Radioactive decay of Th^{232}

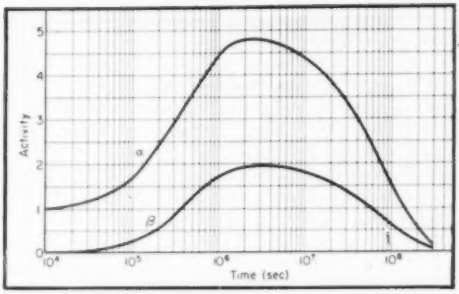

FIG. 2. Radioactive decay of Th^{228}

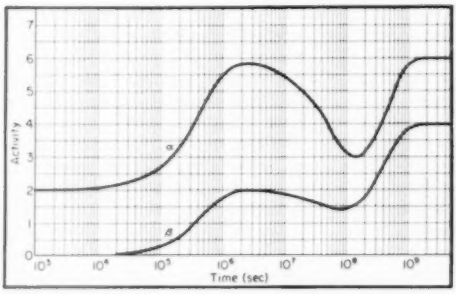

FIG. 3. Radioactive decay of Th^{232} plus Th^{228}

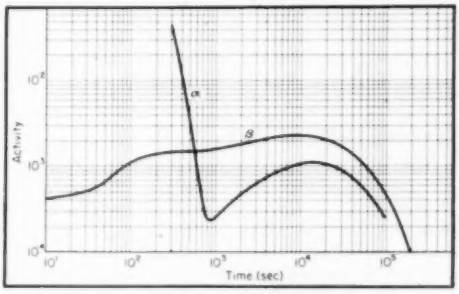

FIG. 4. Radioactive decay of Rn^{220} (thoron)

Bateman equations below, where λ indicates the decay constant and N, the number of atoms. In each series, Tl^{208} is the last radioactive member.

The equations describing the alpha and beta activities are, for:

1. Th^{232}, separated from all other members, in terms of the initial Th^{232} alpha activity (Fig. 1)

$$\sum_{1}^{11}{}^{\alpha} \frac{\lambda N}{\lambda_1 N_1^0} = 6e^{-\lambda_1 t} - 7e^{-\lambda_2 t} + 2e^{-\lambda_4 t}$$

$$\sum_{1}^{11}{}^{\beta} \frac{\lambda N}{\lambda_1 N_1^0} = 4e^{-\lambda_1 t} - 4.79e^{-\lambda_2 t} + 0.79e^{-\lambda_4 t}$$

2. Th^{228}, separated from all other members, in terms of the original Th^{228} alpha activity (Fig. 2)

$$\sum_{4}^{11}{}^{\alpha} \frac{\lambda N}{\lambda_4 N_4^0} = 5e^{-\lambda_4 t} - 4.15e^{-\lambda_5 t} + 0.15e^{-\lambda_8 t}$$

$$\sum_{4}^{11}{}^{\beta} \frac{\lambda N}{\lambda_4 N_4^0} = 2e^{-\lambda_4 t} - 2.29e^{-\lambda_5 t} + 0.29e^{-\lambda_8 t}$$

3. An equilibrium mixture of Th^{232} plus Th^{228} ($\lambda_1 N_1^0 = \lambda_4 N_4^0$), separated from all other members, in terms of the initial Th^{232} alpha activity (Fig. 3)

$$\sum_{1}^{11}{}^{\alpha} \frac{\lambda N}{\lambda_1 N_1^0} + \sum_{4}^{11}{}^{\alpha} \frac{\lambda N}{\lambda_4 N_4^0} = 6e^{-\lambda_1 t} - 7e^{-\lambda_2 t} + 7e^{-\lambda_4 t} - 4.15e^{-\lambda_5 t} + 0.15e^{-\lambda_8 t}$$

$$\sum_{1}^{11}{}^{\beta} \frac{\lambda N}{\lambda_1 N_1^0} + \sum_{4}^{11}{}^{\beta} \frac{\lambda N}{\lambda_4 N_4^0} = 4e^{-\lambda_1 t} - 4.79e^{-\lambda_2 t} + 2.79e^{-\lambda_4 t} - 2.29e^{-\lambda_5 t} + 0.29e^{-\lambda_8 t}$$

(When thorium is separated chemically from the ore, Th^{232} and Th^{228} are in equilibrium if no differential leaching has occurred. The time t will be the time between the actual separation and the measurement.)

4. Rn^{220}, separated from all other members, in terms of the initial alpha activity of Rn^{220} (Fig. 4)

$$\sum_{6}^{11}{}^{\alpha} \frac{\lambda N}{\lambda_6 N_6^0} = 2e^{-\lambda_6 t} - e^{-\lambda_7 t} + 0.0030e^{-\lambda_8 t} - 0.0016e^{-\lambda_9 t}$$

$$\sum_{6}^{11}{}^{\beta} \frac{\lambda N}{\lambda_6 N_6^0} = -0.0014e^{-\lambda_6 t} + 0.0030e^{-\lambda_8 t} - 0.0016e^{-\lambda_9 t}$$

5. An equilibrium mixture of the daughter products of Rn^{220}, separated from the parent ($\lambda_7 N_7^0 = \lambda_8 N_8^0 = \lambda_9 N_9^0 = \lambda_{10} N_{10}^0 = \lambda_{11} N_{11}^0$), in terms of initial Rn^{220} alpha activity (Fig. 5)

$$\sum_{7\text{-}11}^{11}{}^{\alpha} \frac{\lambda N}{\lambda_6 N_6^0} = e^{-\lambda_7 t} + e^{-\lambda_8 t}$$

$$\sum_{7\text{-}11}^{11}{}^{\beta} \frac{\lambda N}{\lambda_6 N_6^0} = 2.10e^{-\lambda_8 t} - 0.12e^{-\lambda_9 t} + 0.02e^{-\lambda_{11} t}$$

6. An equilibrium mixture of Ra^{228} plus Ra^{224}, separated from all other members ($\lambda_2 N_2^0 = \lambda_5 N_5^0$), in terms of the initial Ra^{228} beta activity (Fig. 6)

$$\sum_{2}^{11}{}^{\alpha} \frac{\lambda N}{\lambda_2 N_2^0} + \sum_{5}^{11}{}^{\alpha} \frac{\lambda N}{\lambda_5 N_5^0} = 7e^{-\lambda_2 t} - 7e^{-\lambda_4 t} + 4.15e^{-\lambda_5 t} - 2e^{-\lambda_6 t} - 1.26e^{-\lambda_8 t} + 0.11e^{-\lambda_9 t}$$

$$\sum_{2}^{11}{}^{\beta} \frac{\lambda N}{\lambda_2 N_2^0} + \sum_{5}^{11}{}^{\beta} \frac{\lambda N}{\lambda_5 N_5^0} = 4.8e^{-\lambda_2 t} - e^{-\lambda_4 t} - 2.8e^{-\lambda_6 t} + 2.29e^{-\lambda_8 t} - 2.40e^{-\lambda_9 t} + 0.11e^{-\lambda_{11} t}$$

Examples of the utilization of these

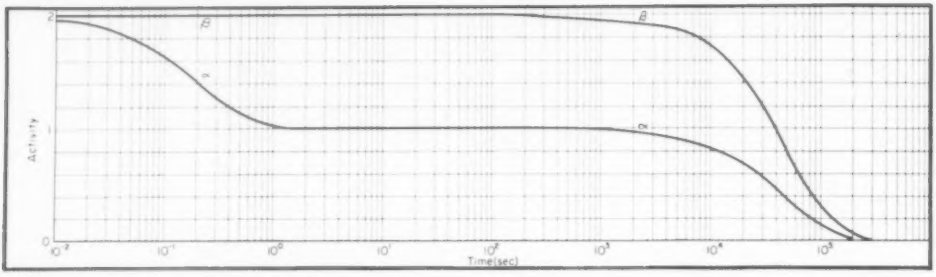

FIG. 5. Radioactive decay of Rn^{220} daughter products

curves would be their application to analysis of thorium products by counting methods and to beta dosimetry calculations.

Counting Methods

The analysis of particular interest for personnel protection would be the determination of thorium in air dust samples by alpha counting methods.

Ore samples should be in radioactive equilibrium and would show the equivalent of six alpha particles per Th^{232} disintegration. Freshly separated thorium metal, on the other hand, has an equivalent of two alphas per Th^{232}. This rises rapidly, as shown in Fig. 3, to an equilibrium value of six alphas within four weeks, and then goes through a decay and second rise. To evaluate the counting results, the date of separation should be known. However, some indication of the date may be obtained by following the alpha decay curve for a period of time, or by the use of the alpha-to-beta disintegration ratio.

The interpretation of beta counting results is complicated by the wide range of energies encountered in the thorium series (Table 2)(3). For this reason, the exact characteristics of the counter used must be known.

In use, the activity curves allow the conversion of measured disintegrations per minute to initial activity of Th^{232}, Rn^{220}, or Ra^{228} according to the type of sample. The initial activity may then be readily converted to weight of isotope or to curies.

It should be realized that air dust samples for thorium analysis give a large alpha count from thoron daughter activity. This decays according to Fig. 4. If the sample is first counted after at least four hours and recounted after several more hours, the long-lived activity may be calculated from the following equation:

$$A = \frac{d_2 - d_1 e^{-\lambda t}}{1 - e^{-\lambda t}}$$

where A = long-lived activity (dpm), d_1 = measured dpm at first count, d_2 = measured dpm at second count, and t = time between counts (λ and t must be in the same units).

After several days, the thoron daughter activity should be negligible. Their decay, as indicated in the equation, is controlled by the 10.6-hr Pb^{212}.

The equations for the activities of Th^{232} plus Th^{228} and for Ra^{228} plus Ra^{224} apply only to these mixtures separated from the rest of the series when radioactive equilibrium holds. Once the separation has been made, the fraction of total activity due to one isotope or the other will change rapidly. In the case of Th, the equilibrium will not be re-established for about 60 yr, and, in the case of Ra, it will take about 20 yr. In the following development, the expressions applying to the alpha activity of thorium will be derived.

If the first separation is made when Th^{232} and Th^{228} are in radioactive equilibrium ($\lambda_1 N_1{}^0 = \lambda_4 N_4{}^0$), in the time between separations:

Th^{232} will decay

$$\lambda_1 N_1{}^{00} = \lambda_1 N_1{}^0 e^{-\lambda_1 t_1} \sim \lambda_1 N_1{}^0$$

Th^{228} will decay

$$\lambda_4 N_4{}^{00}]_{228} = \lambda_4 N_4{}^0 e^{-\lambda_4 t_1}$$

Th^{228} will be formed from Th^{232}

$$\lambda_4 N_4{}^{00}]_{232} = (e^{-\lambda_1 t_1} - 1.40e^{-\lambda_2 t_1} + 0.40e^{-\lambda_4 t_1})\lambda_4 N_4{}^0$$

The total Th^{228} activity will be

$$\lambda_4 N_4{}^{00} = \lambda_4 N_4{}^{00}]_{228} + \lambda_4 N_4{}^{00}]_{232}$$

$$\frac{\lambda_4 N_4{}^{00}}{\lambda_4 N_4{}^0} = e^{-\lambda_1 t_1} - 1.40e^{-\lambda_2 t_1} + 1.40e^{-\lambda_4 t_1}$$

where $N_1{}^{00}$ = number of Th^{232} atoms present at the second separation, $N_4{}^{00}$ = number of Th^{228} atoms present at the second separation, and t_1 = time in seconds between separations. The last equation is plotted in Fig. 7.

The equations previously shown for the activities in terms of $\lambda_1 N_1{}^0$ and $\lambda_4 N_4{}^0$, together with the above expressions, give the activities at the time of measurement after the second separation

$$\sum_1^{\alpha}\Big]_1^{11} \frac{\lambda N}{\lambda_1 N_1{}^0} = 6e^{-\lambda_1 t} - 7e^{-\lambda_2 t} + 2e^{-\lambda_4 t}$$

$$\sum_4^{\alpha}\Big]_4^{11} \frac{\lambda N}{\lambda_4 N_4{}^0} = (5e^{-\lambda_1 t} - 4.15e^{-\lambda_2 t} + 0.15e^{-\lambda_4 t})(e^{-\lambda_1 t_1} - 1.40e^{-\lambda_2 t_1} + 1.40e^{-\lambda_4 t_1})$$

where t = time in seconds between the second separation and measurement.

The total activity will then be the sum of that from Th^{232} and Th^{228}. For any values of t_1 and t, the activity may be calculated from the curves of Figs. 7, 1, and 2.

Similar reasoning may be applied to the beta decay, to the Ra^{228}-plus-Ra^{224} system, and to multiple separations.

Beta Surface Dose Rates

In these calculations, we must consider the amount of thorium in the substance and the range of the radiation in the substance to determine the total energy leaving the surface. This quantity may be converted to standard dose units. This type of calculation has been used to determine the surface dose rates of uranium and thorium metals with some success, and is therefore considered to be applicable

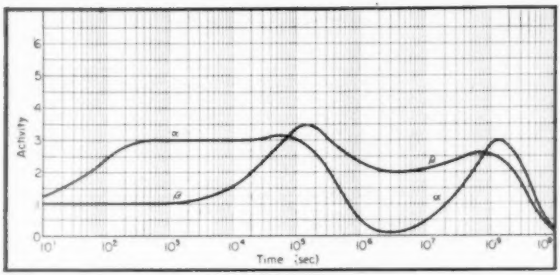

FIG. 6. Radioactive decay of Ra^{225} plus Ra^{224}

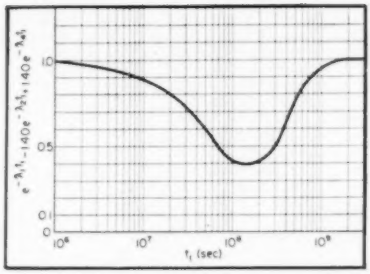

FIG. 7. Total Th^{228} activity after 2nd separation

to other materials. The general derivation, modified from that of Meservey (*4*), and its evaluation are shown below, followed by a sample calculation of the beta surface dose rate from thorium metal.

1. Derivation. If n_0 is equal to the number of beta particles generated per unit volume of source per unit time, from Fig. 8 (in which the element of source volume is a ring around 00′ of radius $r \sin\theta$, cross section $rd\theta dr$, and volume $2\pi r^2$)

$$I = \int_0^{\pi/2} \int_0^R (n_0 2\pi r \sin\theta \, r d\theta \, dr) \left(\frac{dA \cos\theta}{4\pi r^2}\right)\left(\frac{K \, dl}{\cos\theta}\right)$$

where I = ionization per unit time in a volume of air $dA \times dl$ due to charged particles emitted from a semi-infinite distributed source of strength n_0, R = range of particles in source (assumed to be uniform for all particles), and K = number of ion pairs produced by a particle per unit path length in air.

The first parenthetical term denotes the total number of beta particles generated in the source, the second denotes the fraction passing through dA, and the third denotes the ionization in the layer dl at angle θ.

The number of ion pairs per unit volume of air at the surface of the source will be

$$\frac{I}{dA \, dl} = \int_0^{\pi/2} \int_0^R \frac{n_0 K}{2} \sin\theta \, d\theta \, dr = \frac{n_0 K R}{2}$$

From this equation, it is evident that the surface dose can be calculated by assuming that one-half of the particles generated in a source layer of thickness R are emitted perpendicularly from the top surface of the source.

This apparent lack of effect of angular distribution may be explained in the following way: The number of particles emitted from a semi-infinite extended source is (*5*)

$$n = \int_0^{\pi/2} \int_0^R \frac{n_0}{2} \sin\theta \, d\theta \, dr \, dA \cos\theta$$

Thus, the number of particles emitted per unit area is

$$\frac{n}{dA} = \int_0^{\pi/2} \int_0^R \frac{n_0}{2} \sin\theta \cos\theta \, d\theta \, dr$$

$$\frac{n}{dA} = \int_0^{\pi/2} \frac{n_0}{2} R \sin\theta \cos\theta \, d\theta$$

$$\frac{n}{dA} = \left[\frac{n_0 R}{2} \frac{\sin^2\theta}{2}\right]_0^{\pi/2} = \frac{n_0 R}{4}$$

It will be noted that the number of particles emitted from the top surface of a semi-infinite source is equal to ¼ the number of particles generated in a layer of source material whose thickness is equal to the range R of the particles in the material. If all the particles were emitted perpendicular to the surface, this number would be twice as great (i.e., equal to ½ the number generated in a layer of thickness R). Because the particles are emitted from the source nuclei uniformly in all directions, the number emerging is reduced by a factor of 2.

The surface dose (ionization per unit volume of air at the surface) is equal to the number of particles emitted from the surface times *twice* the ionization per unit path length of a particle. This factor of two again arises from the fact that the particles are not moving perpendicular to the surface but distributed in direction between 0 and 90 degrees, and consequently the ionization per unit distance perpendicular to the surface is increased by a factor of 2.

This angular distribution of particles has no net effect on surface dose rate since the two factors of 2, discussed above, exactly cancel each other. This means that the correct surface dose can be obtained by making the assumption that ½ of the particles generated in a layer of thickness R are emitted perpendicularly from the top surface of the source material. It should be noted, however, that the true dose rate as a function of distance from the surface will decrease faster than would be expected under the above assump-

TABLE 2—Radiation Energies

	Series	*α Energies*	*α (Mev)*	*γ (Mev)*
1	Th^{232}		4.0, 4.2	
4	Th^{228}(RdTh)		5.4	0.09
5	Ra^{224}(ThX)		5.7, 5.4	0.25
6	Rn^{220}(Tn)		6.3	
7	Po^{216}(ThA)		6.8	
9	Bi^{212}(ThC)		6.1	0.29, 0.14
10	Po^{212}(ThC′)		8.8	
		β-γ Energies	*β (Mev)*	*γ (Mev)*
2	Ra^{228}($MsTh_1$)		0.002	
3	Ac^{228}($MsTh_2$)		1.55	0.97
				0.91
				0.46
				0.33
				0.06
8	Pb^{212}(ThB)		0.33 88%	0.24 90%
			0.57 12%	0.30 5%
				0.12 2%
				0.18 1%
9	Bi^{212}(ThC)		2.25	0.72 18%
				0.83 16%
				1.03 6%
				1.35 6%
				1.61 12%
				1.80 10%
11	Tl^{208}(ThC″)		1.79	2.62 40%
				0.58 40%
				0.51 20%

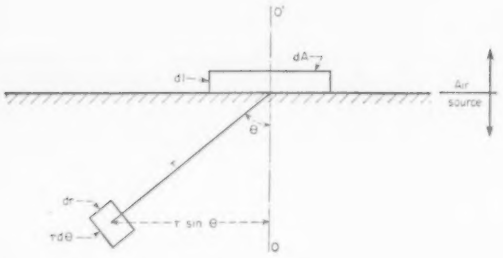

FIG. 8. Radiation from a semi-infinite source

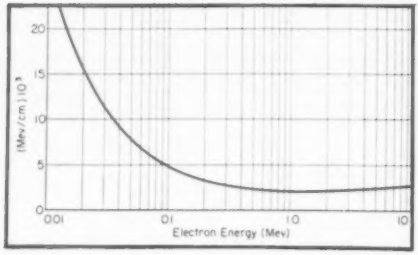

FIG. 9. Energy loss of electrons by ionization and radiation in air

tion since the actual total amount of energy emitted from the surface is the energy carried by ¼ (not ½) the number of particles generated in the layer of thickness R.

2. Evaluation. R and K depend upon the energy of the particular beta particle. Since the beta emission from an isotopic source is known to have a continuous energy distribution, both R and K will vary. For simplification, all the particles are considered to have a single average energy. This value is taken from tables (*6*), where available, or approximated as one third of the maximum energy (Table 2). The use of an average energy to represent the distributed energies of an isotopic beta source is obviously an approximation. However, it is not unjustified for dosimetry calculations.

The number of ion pairs produced per particle per unit path length in air, K, determined for a particular energy, is

$$K = \frac{E_L \times 10^6 \text{ ev/cm}}{32.5 \text{ ev/ion pr}} = 3.08 \times 10^4 \times E_L \text{ ion pr/cm}$$

where E_L is the energy loss per electron per centimeter path of air (Mev/cm). This quantity may be calculated from the Bloch equation (*5*), which is represented in Fig. 9.

TABLE 3—Constants for Calculation

Isotope	*Average energy (Mev)*	*Average range (gm/cm²)*	E_L *(Mev/cm)*
Ra^{228}	0.02	0.0008	1.5×10^{-2}
Ac^{228}	0.52	0.175	2.4×10^{-3}
Pb^{212}	0.12	0.018	4.3×10^{-3}
Bi^{212}	0.73	0.280	2.2×10^{-3}
Tl^{208}	0.60	0.210	2.3×10^{-3}

$N_0 = 1.47 \times 10^7$ dph/gm

In dose calculations, K is better expressed as esu/cm

$$K = (3.08 \times 10^4 E_L)(4.77 \times 10^{-10}) = 1.47 \times 10^{-5} E_L \text{ esu/cm}$$

Also n_0, the number of beta particles generated per unit volume per unit time, is more usually expressed as N_0, the number of beta particles generated per gram of source per unit time. If the range, R, is expressed in grams per square centimeter, we obtain a set of consistent units. This range may be taken from range-energy curves such as those of Glendenin (*7*).

The final expression for surface dose-rate in mrep/hr is

$$\text{dose rate} = 7.34 \times 10^{-3} N_0 E_L R$$

3. Sample Calculation. As an example we will calculate the surface dose rate for thorium metal, both at equilibrium and at three years after separation. These calculations require determination of the dose rate from each isotope and summation of the results. The constants used in the calculations are listed in Table 3.

For nonequilibrium conditions, the dose rate must be modified to correct for the fraction of equilibrium activity present at the time of measurement. Fortunately, the controlling beta decay in the Th^{232} and Th^{228} portions of the series is the first beta decay after the thorium. This allows us to use the Th^{232} and Th^{228} beta curves of Figs. 1 and 2 to determine the fraction of equilibrium activity present.

The equilibrium dose rate for Ra^{228} is 1.3 mrep/hr. This must be modified to obtain the three-year dose rate, and this is best done by taking ¼ of the beta activity shown in Fig. 1. This is an approximation, but a fairly good one.

For Ac^{228}, the equilibrium dose rate is 45 mrep/hr. The three-year dose rate is again approximated by using ¼ of the beta activity shown in Fig. 1.

For Pb^{212}, the equilibrium dose rate is 8.3 mrep/hr. This must be modified by adding ¼ of the beta activity shown in Fig. 1, and ½ of the beta activity shown in Fig. 2.

Only two thirds of the decay follows the Bi^{212} branch, and the equilibrium activity, considering this factor, is 44 mrep/hr. It is modified in the same way as Pb^{212} for the nonequilibrium conditions.

One third of the activity follows the Tl^{208} branch, and the resulting dose rate is 17 mrep/hr. It also is corrected in the same way as Pb^{212}.

Results are summarized in Table 4.

* * *

The authors wish to acknowledge the assistance of Miss Naomi Hallden in preparing the graphs for this paper.

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TABLE 4—Calculation Results

Isotope	*Equilibrium dose rate (mrep/hr)*	*Fraction from* Th^{232}	*Fraction from* Th^{228}	*Three-year dose rate*
Ra^{228}	1	0.2	0	0
Ac^{228}	45	0.2	0	9
Pb^{212}	8	0.2	0.3	4
Bi^{212}	44	0.2	0.3	22
Tl^{208}	17	0.2	0.3	8
Total =	115		Total =	43

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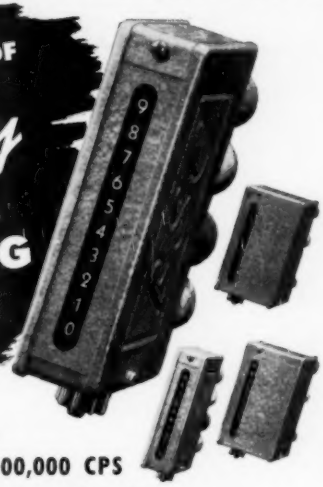

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BOOKS

Fundamentals of Atomic Physics, by Saul Dushman, McGraw-Hill Book Company, Inc., New York, 1951, x + 294 pages, $5.50.

This book was written for a special, and highly important, audience. In his preface, the author states that the book is the outgrowth of a series of lectures given to groups of outstanding high school teachers of science. These teachers were granted fellowships by the General Electric Company for the purpose of "enlarging each Fellow's grasp of new developments in the physical sciences." The book is thus designed for persons who are well grounded in the physical sciences but not primarily physicists or chemists, and who are willing to work hard to acquire some quantitative knowledge of a variety of phenomena in atomic and nuclear physics.

The contents of the chapters reflect the requirements of this specialized group. The first chapter is an outline of the history of physics, intended to place recent developments in proper perspective; the second chapter is a brief review of the mathematics needed, through partial differential equations. Subsequent chapters deal with the kinetic theory of gases, with behavior of electrons in vacuo, with photoelectric effect, and with theory of spectra. The last three chapters constitute a survey of experimental nuclear physics, including fairly detailed descriptions of the major types of particle accelerators.

The author touches briefly on quite a number of advanced topics in each of these fields. Thus, the discussion of kinetic theory includes one-half page on the interdiffusions of two gases. The reader is shown the Schroedinger equation in one dimension and then is later taken, in less than one page, from the three-dimension Schroedinger equation for the hydrogen atom to its stationary state eigenvalues. Three pages suffice to cover fission, chain reactions, and methods of separating U^{235} and of producing plutonium.

The book therefore tends to be quite encyclopaedic, and obtains coverage of many topics at the expense of stating results without derivation. One also frequently finds it necessary to refer to material in subsequent chapters to understand a statement in an earlier chapter.

The book contains occasional misprints and a few minor errors in fact. For example, it was the cavity rather than the split-anode magnetron which found important applications in World War II (p. 105), and the Berkeley linear accelerator is designed to accelerate protons to extremely high energies, and not (p. 240) electrons, protons and deuterons.

This reviewer would recommend "Fundamentals of Atomic Physics" to prospective readers with a good knowledge of general science who seek an authoritative introduction to atomic and nuclear physics. He would expect such a reader to find many points which excite his imagination and lead him to further study.

The author has a lucid and interesting style in dealing with necessarily compressed subject matter. This reviewer would not recommend the book for use as a collegiate text in atomic physics, since it deals with the subject matter of three intermediate or first-year graduate courses (Kinetic Theory, Atomic Structure, Nuclear Physics) in a space too short to permit full development. Persons teaching these courses would, however, find in the book many interesting examples not usually found in texts.

—Joseph B. Platt
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Principles of Quantum Mechanics (Non-Relativistic Wave Mechanics with Illustrative Applications), by William V. Houston, McGraw-Hill Book Co., Inc., New York, 1951, vii + 288 pages, $6.

This introduction to non-relativistic wave mechanics is unusual in the brevity of its outline of the general structure of the theory, and in the choice of material for the detailed illustrations that make up more than half of the book.

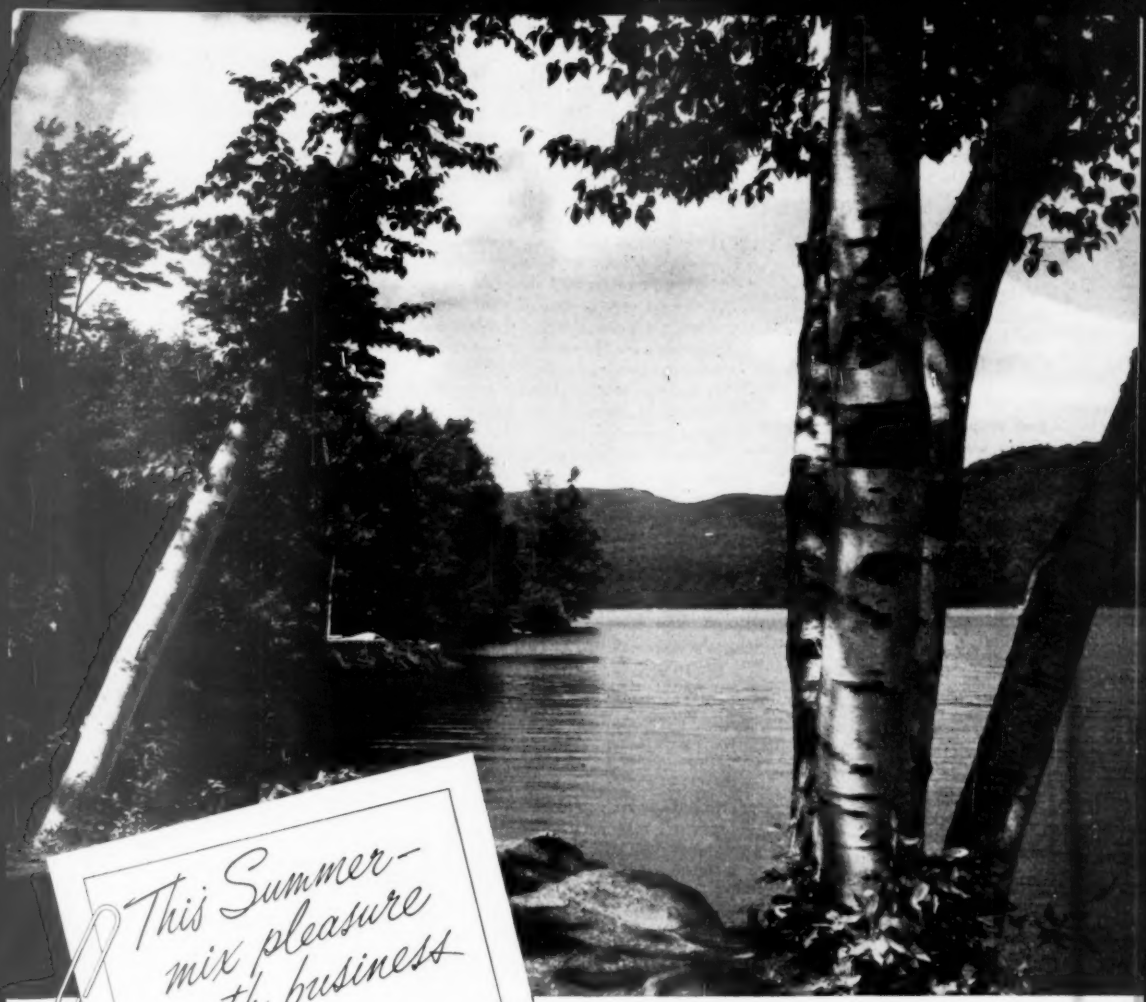
The first 115 pages contain a discussion of the inadequacy of classical mechanics for the description of atomic systems, a summary of the basic ideas of wave mechanics, and brief descriptions of the standard methods for solving wave mechanical problems. This brings to completion a survey of the whole theory, in a space much less, for instance, than the 172 pages devoted to introductory discussion alone in Bohm's "Quantum Theory." This brevity in the formal presentation of the quantum theory is attained at some sacrifice in the completeness with which certain basic ideas of the theory are presented and discussed; in fact, many important ideas are first introduced in the portions of the book devoted to *Applications,* which thus assume a greater importance in the presentation of the theory than one might at first suppose from the formal organization of the book. The discussion of approximation methods is also extremely brief, four pages being devoted to the perturbation method, three to the method of variation of constants, and one to the ordinary variation method.

Some of the basic ideas of the theory are stated as formal postulates: the interpretation of $\psi^*\psi$ as a coordinate probability distribution and of $\phi^*\phi$ as a momentum probability distribution; the operator substitution method for constructing operators representing functions of coordinates and momenta; the form of the general wave equation. This method of presentation is useful in giving form, precision, and emphasis to the discussion, and might well have been carried farther, particularly in the chapter on characteristic functions.

The latter chapter seems, to the reviewer, to be the weakest part of the book. The general discussion is neither precise nor complete, many important points being mentioned for the first time in the later chapters on *Applications.* Furthermore, some basic ideas are stated without emphasis or adequate explanation of their connection with the rest of the theory, while other ideas are more implied than stated. (The clear implication that characteristic functions must be quadratically integrable is contradicted by two examples in the same chapter.)

The detailed presentation of certain applications of the theory takes up almost three fifths of the book, and is its most characteristic feature.

The part on *Applications to Spectroscopy* shows the influence of the classical work of Condon and Shortley, and should be a valuable addition to textbook literature. A chapter on one-electron spectra brings together topics ranging from hydrogenic spectra to the Paschen-Back effect. The chapter on two-electron spectra is clear and detailed, and contains statements and illustrations of many basic ideas and



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techniques; to the reviewer it seems to be the high point of the book. It is surprising, however, to find that so detailed a presentation of the perturbation theory of atomic spectra is accompanied by no reference whatsoever to the methods used in finding the atomic orbitals from which the perturbation calculations start.

The part on *Applications to Collision Problems* is clear but conventional in the choice of material.

The part on *Applications to Electrons in Solids* is, however, most unusual in the choice of material. Its first chapter opens with a statement of the basic assumptions of quantum statistical mechanics. The density operator for a canonical ensemble is defined, but its usefulness in calculations is not made very clear. From this point, the discussion turns to ordinary statistical mechanics, and the chapter concludes with derivations of the Fermi-Dirac and Bose-Einstein distribution functions by the method of steepest descents. The chapter on the behavior of an electron gas which follows has practically nothing to do with wave mechanics; it includes discussions of the Fermi-Dirac distribution function, thermionic emission, and electrical conductivity. The section ends with a chapter on a subject to which Dr. Houston has made important contributions, that is, motion of an electron in a periodic potential. This develops the idea of Brillouin zones at some length, using both the approximations of tightly bound and almost free electrons.

The final part, *Application to Electromagnetic Radiation*, is made up of a chapter on the quantization of the electromagnetic field, followed by one on the interaction of radiation and matter. The basic theory is presented in unusual detail, but the only application given is the derivation of the probability of a spontaneous transition with emission of dipole radiation.

The book contains a few errors of detail, usually where some aspect of the theory is being sketched in, rather than developed in full. One of these slips needs mention here, since it comes within the field of Dr. Houston's special competence. On page 229 it is stated that all solutions of the one-dimensional stationary-state equation with periodic potential have the form $U = u_k e^{ikx}$, where u_k is periodic with the period of the potential; actually, linear combinations of U_k with U_{-k}, which also are solutions of the equation, do not in general have this form. A similar slip occurs on page 68, where it is stated that for a free particle "the energy-characteristic states are also characteristic of momentum, since the energy is a function of the momentum only." Only the converse of this statement is true, since combinations of characteristic functions for different vector momenta with the same magnitude are energy-characteristic functions, without being characteristic functions for the vector momentum or its components.

On the whole, this book has the virtues of clearness and brevity. Its most valuable feature, however, is likely to be the careful working out of illustrative material in the latter sections, particularly that on spectroscopy.

—Hubert M. James
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BOOKS RECEIVED

Automatic and Manual Control, edited by A. Tustin, Academic Press Inc., Publishers, New York, 1952, xi + 584 pages, $10.

This volume contains the proceedings of the Conference on Automatic Control held in Cranfield, England, in July, 1951. Britain's Department of Scientific and Industrial Research arranged the sessions, with the support of the Institute of Electrical Engineers and the Institution of Mechanical Engineers. A comprehensive meeting, it included papers on educational problems, general theory, process control, nonlinear problems, systems working on intermittent data and step-by-step servos, the human operator, and particular applications including analog computers and other devices.

To make the volume more useful to the reader uninitiated in particular aspects of the subject, the editor has made helpful suggestions for supplementary reading. It should be a valuable reference to anyone interested in control-equipment design.

The Auger Effect and Other Radiationless Transitions, by E. H. S. Burhop, Cambridge University Press, New York, 1952, xiv + 188 pages, $5.50. One of the Cambridge Monographs of Physics. (*To be reviewed.*)

Symposium on Radiobiology—The Basic Aspects of Radiation Effects on Living Systems, edited by James J. Nickson, John Wiley & Sons, Inc., New York, 1952, xii + 465 pages, $7.50. Proceedings of the conference at Oberlin College in 1950. (*To be reviewed.*)

Handbook of Engineering Fundamentals, 2d Ed., edited by Ovid W. Eshbach, John Wiley & Sons, Inc., New York, 1952, x + 1,214 pages, $10.

A revision of the first edition published in 1936, this volume incorporates many of the units and international standards that have changed or been clarified since that date and gives more emphasis to the more widely used MKS and rationalized MKS system of units. The engineering tables have been enlarged to include standard structural sizes for aluminum, together with data on tangents and offsets. The section on fluid mechanics has been rewritten into two parts, one dealing with the mechanics of incompressible fluids, and the other with aerodynamics. It is apparent that the contributors have had the problem inherent to all handbooks, that is, the problem of trying to provide information of interest to all engineers and anticipating, with their illustrations, fields of common application. In this respect, they have not strayed too far afield from the original purpose of the handbook which was to include in a single volume "those fundamental laws and theories of science which are basic to engineering practice."

Imperfections in Nearly Perfect Crystals, edited by W. Shockley, J. H. Hollomon, R. Maurer, and F. Seitz, John Wiley & Sons, Inc., xii + 490 pages, $7.50.

Twenty authors have contributed 17 articles to this summary of scientific theories and experimental facts on crystal imperfections and grain boundaries. It is the record of a symposium held at Pocono Manor, Pa., in 1950 and sponsored by the National Research Council. Lattice imperfections are providing the answers to a number of problems in the branches of science dealing with solids, and those persons concerned will probably find much of interest in this volume.

Quantitative Chemical Analysis, by Charles W. Foulk, Harvey V. Moyer, and William M. MacNevin, McGraw-Hill Book Company, Inc., New York, 1952, ix + 484 pages, $5.

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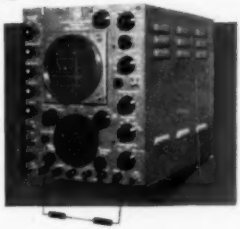

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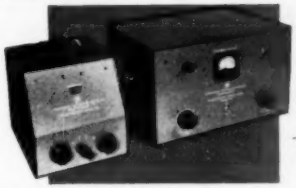

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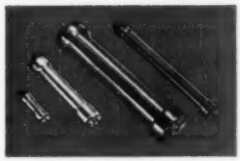

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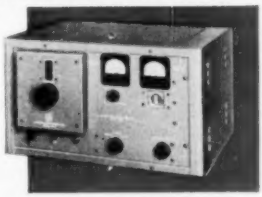

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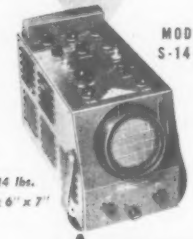

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OTHER LITERATURE

Radiological Decontamination in Civil Defense (TM-11-6). A 31-page Federal Civil Defense Administration technical manual based on the results of research by the U. S. Naval Radiological Defense Laboratory in San Francisco. Besides decontamination methods and equipment, it offers suggestions on aging, sealing, removing, and storing "hot" materials. *GPO, Washington 25, D. C., $0.15.*

Handling Radioactive Wastes in the Atomic Energy Program. A 28-page technical pamphlet published by the U. S. Atomic Energy Commission in which types and sources of radioactive wastes are described and methods for their safe handling outlined. Wastes both in the atomic-energy industry itself and those resulting from radioisotope distribution are considered. Appendices include lists of AEC advisory committees and AEC-supported waste-disposal research and development. *GPO, Washington 25, D. C., $0.15.*

The National Research Council Review—1951 (NRC Report 2560). A 285-page description of the work of Canada's NRC carried out during 1950, together with some notes on early work in 1951. The accomplishments and administrative details of the Atomic Energy Project occupy 30 pages. Some nuclear research and work involving radioisotopes being done by NRC's various other divisions is outlined elsewhere in the report. *National Research Council, Ottawa, Canada, $0.75.*

Geologic Map of the Henry Mountains Region, Utah (Map OM 131). Released in advance of publication of the U. S. Geological Survey report of which it is part, this is a color map, 29 × 50 inches, of an area in south-central Utah that contains carnotite, a uranium- and vanadium-bearing mineral. It is offered as an aid to prospecting, mining, and development in the region. *Distribution Section, Geological Survey, Denver Federal Center, Denver, Colo., $1.*

Bibliography on Geiger-Mueller Photon Counters, by Edward J. Walker (National Bureau of Standards Report 1050). A total of 81 references to articles appearing in English, German, French, Russian, and Italian; comments or abstracts are included. *Office of Scientific Publications, National Bureau of Standards, Washington 25, D. C.*

Technion Yearbook (1951). The 25 articles in this 360-page annual embrace two subjects: *science—servant of mankind*, and *Israel—democracy in action*. "Atoms for Peace," an article by Paul C. Aebersold, AEC Isotopes Division chief, appears in the science section, as do references to the profession of nuclear engineering in "Engineering Education in a Changing World," by William Allan. *American Technion Society, 80 Fifth Avenue, New York 11, N. Y., $3.*

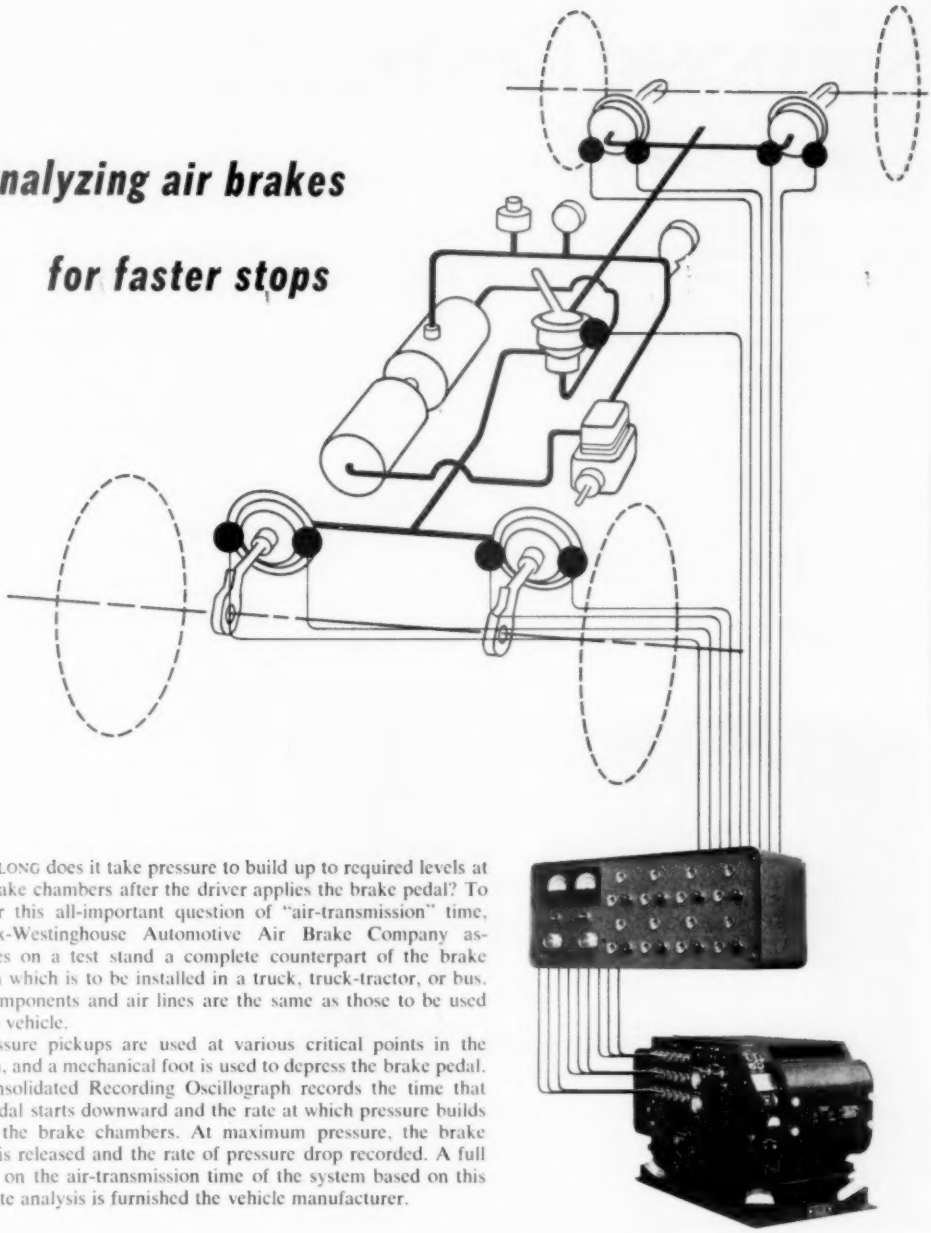
BOOK NEWS

• **Russian-English dictionary.** The National Science Foundation has allocated $39,300 for a series of studies that may eventually lead to the compilation of a new, comprehensive Russian-English scientific dictionary. Columbia University is undertaking the project for NSF.

• **Public health awards.** Lists of approved U. S. Public Health Service research grants and fellowships are now being published three times yearly in the journal *Public Health Reports.*

• **Symposia proceedings.** The papers and discussions presented at two recent radiation symposia are being prepared for publication. They are proceedings of the symposium on "The Radiation Sterilization of Antibiotics," held in Washington, D. C., February 14, 1952, and sponsored by Radiation Engineering Laboratory of the Stanford Research Institute, Stanford, California, and the Fifth Annual Biology Research Conference which considered "Some Aspects of Microbial Metabolism." The latter was arranged by the Biology Division of Oak Ridge National Laboratory and held at Oak Ridge, Tenn., April 10–11, 1952.

Analyzing air brakes for faster stops



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NUCLEONIC EVENTS

Member of Joint Committee Calls for AEC To Build Industrial Power Reactor by 1954

Construction by 1954 by the Atomic Energy Commission of a power-producing nuclear reactor which would serve the electricity needs of a city of 100,000 was called for last month by Rep. Henry M. Jackson, member of the Joint Congressional Committee on Atomic Energy. A reactor of this type could be built for $30-40-million, according to Mr. Jackson, and would supply power at "commercially attractive prices," with the value of the plutonium produced taken into account.

At a conference on the legal and industrial implications of atomic energy at the University of Michigan, Mr. Jackson cited the production of token amounts of electricity by the experimental breeder reactor in Idaho and said that it is now time that the development of nuclear power be taken "out of the laboratory and into the production shop."

"The Commission has been working on designs of such reactors for six years," he said; "its files are filled with blueprints of promising models . . . None of the designs for a power-producing reactor is as yet perfect. If we carried on our researches for another ten years, we could without doubt build a more efficient reactor than can be constructed today. . . The problem now is to move from . . . a test scale to actual construction."

Mr. Jackson told NUCLEONICS that AEC might obtain money for the construction of a power reactor in a supplemental appropriations request when Congress reconvenes in January.

AEC Office of Industrial Development To Help Industry Apply Atomic Energy

A positive effort to single out ideas and techniques developed in the Government's atomic energy program which might have industrial applications will be the most important function of the recently established AEC Office of Industrial Development (OID), according to its director, W. L. Davidson. In a talk to the National Conference of Business Paper Editors in Washington, Davidson said that an attempt would be made to "arouse the enthusiasm of private industry" to explore such ideas with its own money.

In addition, OID will assist General Manager Marion Boyer on problems relating to industry and will aid in the administration of the present industrial participation program.

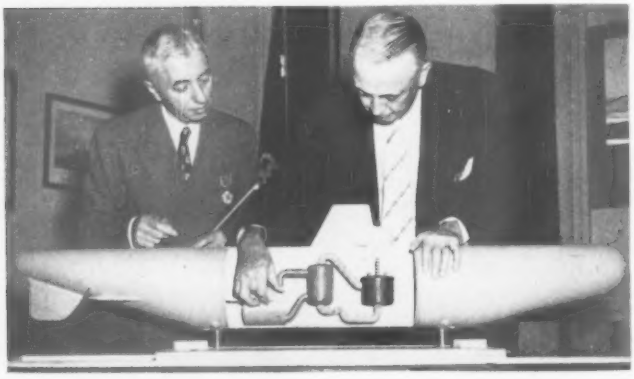
Some of the problems already tossed into Davidson's lap are:

1. What is an equitable patent clause for the contracts covering a second round of studies by self-financed industrial teams looking into the possibility of private ownership and operation of nuclear power plants?

2. Is the requirement that a company explain in detail the nature of the research problem it proposes to tackle stifling the use of radioisotopes by American industry?

3. Is the current research program seeking commercial applications for gross fission products an overly ambitious one?

4. Should AEC create a permanent advisory committee representing the utilities industry which would have certain responsibilities on problems related to nuclear power? Such a



MODEL OF THE NAUTILUS, NUCLEAR POWERED SUBMARINE, IS BEING SHOWN to Dan Kimball, Secretary of the Navy, by Capt. H. Rickover (left), chief of the Naval Reactor Branch, Reactor Development Division, AEC. The keel of the submarine was laid by President Truman on June 14 at the South Yard of the Electric Boat Division of the General Dynamics Corp., Groton, Conn. The nuclear and steam power plant for the sub will be built by Westinghouse and Argonne National Laboratory. The fuel will be uranium, and high-temperature, high-pressure water will be the heat-exchange medium for transferring heat from the reactor to the boiler of the steam-turbine propulsion plant. A land-based prototype reactor and steam propulsion system is being erected at the Reactor Testing Station, Arco, Idaho. It will be the power plant of an actual submarine, in a portion of a submarine hull, and will be as identical as possible with the seagoing hull and power plant. Construction of another land-based prototype of a nuclear power plant for submarines was authorized by AEC on Feb. 21, 1952. Design and construction of this reactor is under the supervision of the Knolls Atomic Power Laboratory of General Electric Co. This prototype will be used for final development work leading to construction of a submarine propulsion reactor with neutrons of intermediate energy. This second submarine will also be built by Electric Boat.

committee was recommended by the Sporn study group a year ago (NU, Aug. '51, p. 78).

Since he stepped into this job on May 1, Davidson has talked to representatives of more than 40 companies. About half of this number want to sell products or engineering services to the AEC, whereas the others want "something other than money from the AEC." Since "every laboratory and contractor involved in AEC activities is a potential customer" of the first group of companies, a direct contact is suggested for them.

The second group of firms has varied interests. According to Davidson, "Some desire technical information applicable to their technical activities, others want to know how future developments in the atomic field may affect their present endeavors, still others want to get into the atomic energy business with their own funds."

Sen. McMahon Dies, Was Atomic Committee Head

Brien McMahon, 48-year-old Senator from Connecticut, died on July 28. Senator McMahon was chairman of the Senate-House Committee on Atomic Energy, and author of the Atomic Energy Act of 1946 which bears his name.

He had been head of the special Senate committee created to study his bill and rival proposals. Senator McMahon strongly insisted on civilian rather than military control of the atomic energy program.

In 1951, Senator McMahon recommended that annual appropriations for atomic energy be increased from $1-billion to $6-billion. The recently increased budget of AEC is a reflection of that recommendation.

France Starts Long-Range Atomic Energy Program

The French National Assembly has approved a 5-year, $107-million program of nuclear research aimed at eventually making France a major producer of industrial atomic energy.

The new plan provides for the construction of a French atomic research center equipped with two reactors, one of 50,000 kw and the other of 100,000 kw, two small accelerators, and housing for the personnel of the center.

France now has in operation only a 5-kw reactor nicknamed "Zoe" and is

The Editors Hear . . .

▶There is no such thing as "enough" atomic bombs, according to Congressman Henry M. Jackson, member of the Joint Committee on Atomic Energy. This means that industrial firms which build dual-purpose nuclear reactors have an unlimited market for the plutonium they produce.

▶AEC is ready to move on its $3-billion expansion. Chairman Gordon Dean told NUCLEONICS that preliminary discussions earlier this year with prospective contractors showed that enough companies were available to do the work.

▶The expansion will boost the number of people working on the program. AEC will add 692 to increase its total staff to 7,140. Contractors will need 4,500 more scientists and engineers.

▶The Materials Testing Reactor in Idaho, which went critical on March 31, reached rated operating level on May 22.

▶L. R. Hafstad, director of AEC's Division of Reactor Development, says that the cost of the power plant for a *nuclear* submarine should approximate that of the high-speed subs presently being considered. The power for the latter would cost the Navy $1.50 per kilowatt-hour. This compares with 2¢/kwh for a capital ship (cruiser or battleship) and 8¢/kwh for a conventional slow sub.

▶The maximum permissible radiation exposure of 0.3 roentgen per week can probably be exceeded in a single exposure by 100 r with no apparent harm to the individual, according to Dr. John Bugher, director of AEC's Division of Biology and Medicine.

▶The limitation on private ownership of reactors and the prohibition on the awarding of exclusive patents in the reactor field were included in the Atomic Energy Act of 1946 because of the lack of knowledge of the full potential of atomic energy and because of the hope for international control, says Bennett Boskey, former deputy general counsel of AEC. He says that private ownership would not hinder the development of an international control plan. The U. S. Government would continue to exercise control within the country because of its ownership of the reactor fuel and its control over plant safety and security.

▶The risk of investment in nuclear power plants is not as great as many people think, according to Walker Cisler, president of the Detroit Edison Co.

▶Although it might be tough to know exactly where to draw the line, Carroll Wilson, former General Manager of AEC, thinks it is possible to separate weapons technology from a reactor technology. Such a policy would permit more nonsecret work in the reactor field.

▶Canada expects to have an experimental power reactor in operation in four to six years, and commercial nuclear power available in ten years.

▶With permission of AEC Chairman Dean, Senator Maybank revealed last month the previously secret information that 500,000 gallons of water per minute will be needed to cool the Savannah River reactors.

▶Australian officials hope that within 10–15 years it will be possible for nuclear power to supplement their dwindling energy reserves.

▶Despite the hope of several universities that they can get going immediately with their plans for building research reactors, AEC has delayed establishing a policy for such matters.

building a second reactor of 1,000–1,500 kw.

The two larger reactors called for under the 5-year plan will enable France to produce radioisotopes in sufficient quantities to meet all French needs and leave a surplus for export. They also will produce plutonium for use in developing industrial applications of atomic energy.

The French government will spend $4.3-million to get the plan started this year. Expenditures will rise to a peak of $25-million in 1956 as construction is completed and then drop to an annual rate of $10-million in 1957 and afterward.

Reactor Study Team Asks AEC to Build Pilot Plant

Monsanto Chemical Co. and Union Electric Co. of Missouri have decided against the immediate investment of their own money in the design and construction of a nuclear power plant. Instead they have asked the Atomic Energy Commission to build a pilot plant for preliminary experimental work.

This recommendation was made after a year's study by the two companies, acting as one of four teams investigating the economic feasibility of nuclear power. This team plans to continue its reactor studies at its own expense but, before making any sizable investment, it wants to see the outcome of AEC pilot plant work.

In addition, according to a report made by Edwin J. Putzell, Jr. of Monsanto at a University of Michigan conference on June 26, the companies prefer delaying building a reactor until a satisfactory solution is found to the legal problems of private ownership of nuclear power plants and limitations on private patent rights.

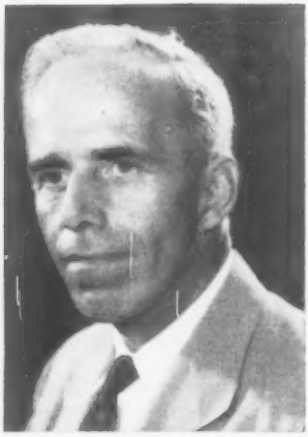
AEC Gets $2.9-Billion for Plant Expansion

In an eleventh hour decision, made just before adjournment, the 82nd Congress revised upward its action on President Truman's request for $3.1-billion for atomic energy plant expansion. Nearly a billion dollars was added to Congress' original decision on the request for supplementary funds. The total agreed upon is almost $2.9-billion.

It is expected that the new funds will allow the following expenditures: expansion of the Oak Ridge plant, $465-million; expansion of the Paducah, Ky., plant, $412-million; additional facilities at a new site in the Ohio Valley, $1,260-million; and additional facilities at the Savannah River, S. C., plant, $171-million.

According to Gordon Dean, chairman of the Atomic Energy Commission, "The setting in which this request (for supplementary funds) is made stems from recent revolutionary developments in the field of atomic weapons technology."

Chairman Dean also pointed out that AEC would actually spend only $600-million of the request during fiscal 1953.



GEORGE R. PROUT, vice president and general manager of Hanford, operated by the General Electric Co., has been replaced by WILFRID E. JOHNSON as general manager. Mr. Prout is now in charge of nucleonics projects at GE in Schenectady

Military Blamed for Low Uranium Output

Increased effort should be devoted to discovery and production of uranium, according to a recently released report of the Raw Materials Subcommittee of the Joint Congressional Committee on Atomic Energy.

The Subcommittee objects to the official doctrine that uranium ore supplies are rigidly limited, and "feels strongly that responsibility rests squarely upon the military to propose assigning to atomic production whatever share of the total national defense budgets as will best guard our country and that this responsibility can in no wise be avoided on the basis that uranium raw material must limit output."

According to the report, "the quantity of uranium ore obtainable rises or falls with the degree of effort exerted to this end." The output of uranium ore in the United States is a fraction of the total output of the free world, and likewise a fraction of our total demands. The subcommittee feels that in the interests of national defense, it is unwise to place reliance on continuing supplies of uranium from the rest of the world.

Atomic Energy in Brazil Aided by U. S. Scientists

Five U. S. scientists are spending several months in Brazil acting as advisers to the Brazilian government in the development of an atomic energy program there. The five are I. I. Rabi, Columbia University; John Marshall and Herbert Anderson, University of Chicago; Robert Champion, Stanford University; and J. H. Hayner of AEC. The scientists are not acting as representatives of their institutions.

According to Admiral Alvaro Alberto, head of the Brazilian National Council of Research, a small cyclotron is now being built in Chicago for Brazil, and will be used to train technicians. Later a large cyclotron, modeled on the one at the University of California, will be built at Rio de Janeiro.

Admiral Alberto said that "possibly within a few years" Brazil would have its first reactor in operation. The raw

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materials problem has been helped by an authorization to acquire the three rich deposits of uranium ores that have been found in the state of Minas Geraes. The council plans to build processing plants for the uranium ores.

Uranium Miners Show No Ill Effects of Radiation

Detailed physical examinations of over 1,100 workers in uranium mines and mills in Colorado, Utah, New Mexico, and Arizona have revealed no evidences of health damage from radioactivity, according to an interim report released by the Public Health Service of the Federal Security Agency.

The examinations are part of a study of occupational health conditions in the uranium industry that has been under way since 1950. The study is expected to continue for the next several years. The miners and millers will be reexamined periodically, and continued checks will be made of the working environment.

Plans to study and control harmful exposures were started when the uranium industry began to reach sizable proportions in this country.

In instances in which the investigators encountered dangerous amounts of radiation, the mine operators were immediately advised not only to reduce the levels of radiation in the mines but also to take additional steps to protect the health of individual workers. Among these steps have been the adoption of proper ventilation practices as well as other measures to reduce the dusts found in the mines.

Cooperating with the Public Health Service and the Colorado State Department of Public Health in this study are the Atomic Energy Commission, the U. S. Bureau of Mines, the Los Alamos Scientific Laboratory, the Navy Radiological Defense Laboratory, the U. S. Bureau of Standards, and the State health departments of Utah, New Mexico, and Arizona.

10 European Nations Plan Lab with Cosmotron

The world's biggest nuclear research laboratory, a cooperative venture of 10 nations, will be built in either Denmark or Switzerland. This project was first discussed about a year ago (NU, Sept. '51, p. 80), and more complete plans were made at the recent conference of the European Council for Nuclear Science held in Copenhagen (NU, June '52, p. 75).

The biggest item in the lab will be a 3-10-Bev cosmotron. This will be a 7-year design and construction project, and will cost an estimated $14-million.

Also planned for the lab is a 500-Mev cyclotron.

The council, which organizes and supervises study groups for the project, was formed in February when representatives of the participating nations met

Raw Materials Developments

United States. The University of Nevada has been awarded a $60,000 contract by the Atomic Energy Commission for developmental studies of methods of processing uranium ores and concentrates. The studies will be concerned with beneficiation of low-grade ores and extractive metallurgy for recovery of uranium from ores and concentrates.

Australia. MELBOURNE (*McGraw-Hill World News*)—The great uranium deposits at Rum Jungle in the Northern Territory are believed to be extremely rich, but large-scale exploitation would have to follow an accurate survey and much developmental work. Private American enterprise will probably do the mining and processing.

In the meantime, it is understood that first sales of Australian-mined uranium have been made to the U. S. at what is officially described in Australia as "a very good price." (The U. S. Atomic Energy Commission had offered the Australian Cabinet about $3.50 a pound for uranium oxide.)

In their agreements with buyers of uranium, the Australians have made it clear that sufficient quantities of uranium should be reserved for future Australian requirements. An Atomic Energy Bill just passed grants the Commonwealth full authority to control production of uranium in Australia.

West Germany. The Black Forest uranium finds are worth mining, according to an investigation by the Geological Institute of Land Baden. Uranium concentration in the ore in the field is supposed to be considerably in excess of 0.1%. The investigations are being carried out in a 115-square-kilometer district around Wittichen.

in Geneva under UNESCO auspices.

The participating nations are France, West Germany, Italy, Belgium, the Netherlands, Switzerland, Denmark, Norway, Sweden, and Yugoslavia.

Yale and AEC to Share Cost of New Accelerator

Yale University and the Atomic Energy Commission will share the cost of construction of a 20-Mev linear electron accelerator to be built at the new atomic energy laboratory on the Yale campus. The machine is expected to produce intensities 5–10 times higher than present linear accelerators.

The project is under the direction of Howard Schultz, assistant professor of physics. A. Whitney Griswold, president of the university, said the project would "inaugurate a whole new research program in nuclear physics."

Estimates are that the accelerator and associated equipment will cost about $350,000.

The space for the accelerator will be below ground level. It will be the first unit of a large new physics building for which funds are now being raised.

Three New Linear Electron Accelerators in England

A 15-Mev linear electron accelerator has been built for the Atomic Energy Research Establishment, Harwell, England. The machine, biggest of its type in the country, is now undergoing final testing before delivery to Harwell.

The accelerators will be used for basic research, including reactor-design studies.

A similar 15-Mev machine, to be used for cancer research, is now being built for St. Bartholomew's Hospital. A 4-Mev linear accelerator, currently in the development stage, will be used for clinical work at the Royal Victoria Hospital, Newcastle-on-Tyne.

IN BRIEF

• **Low-cost 6-Mev X-rays.** A linear accelerator designed to produce 6-Mev X-rays, and modeled on Stanford's billion-volt accelerator, is under construction at Stanford University. Edward L. Ginzton and Henry S. Kaplan are building the machine under grants totaling $63,000 from the American Cancer Society and the National Cancer Institute. They say

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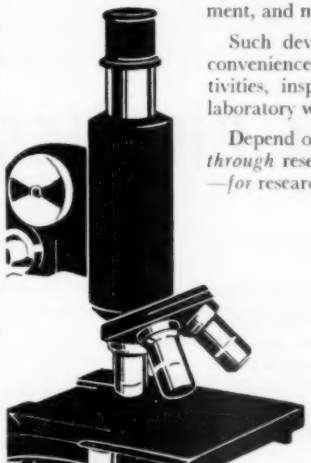
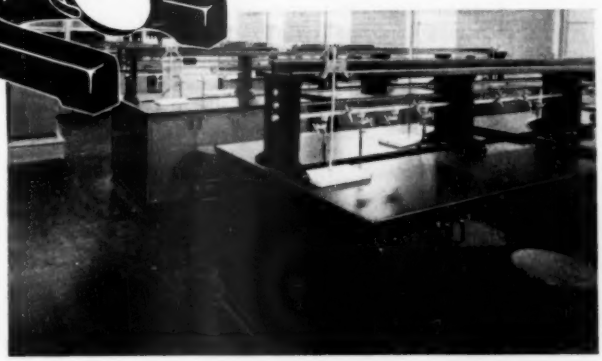


FUME HOOD No. 3602 for Radioisotope Laboratories. Design approved for use by Oak Ridge Institute of Nuclear Studies.



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that such a machine could be marketed for not much more than $18,000, which is what a 2-kv X-ray generator costs now.

• **I^{131} elevator control.** *An automatic elevator at Southern Pacific Hospital, San Francisco, will use radioiodine to control its stopping. Clay Bernard, codeveloper of the control, said it will position the elevator within 0.005 in.*

• **ORINS contract.** AEC and the Oak Ridge Institute of Nuclear Studies have signed a contract for the Institute to continue operation of its programs for another 5 years.

• **Health physics building.** *A contract to build a health physics building at the AEC's new Rocky Flats Plant near Denver has been awarded to Craftsmen Construction Co., of Santa Fe.*

• **Summer training at Hanford.** This summer 125 college graduates in science and engineering will take part in the rotational training program at the Hanford Works, Richland, Wash. This is the third year in which young holders of B.S. and M.S. degrees have been recruited for the program, which is designed to prepare young scientists to fill responsible positions in the atomic energy field.

NUCLEAR NEWSMAKERS

Buford Sparks has replaced **Edward Sargent** as manager of the Atomic Energy Commission's Cleveland, Ohio, Area.

Gordon E. Dunlap has been appointed chief of the metallurgical Branch of the production division, New York Operations Office, AEC.

George L. Weil has resigned as assistant director of the reactor development division of AEC. He intends to become a private consultant in reactor design and engineering, dealing particularly with experimental nuclear power plants for private organizations.

Allen V. Astin is the new head of the National Bureau of Standards. He has been acting head of the bureau since **Edward U. Condon** resigned last October.

Max E. Smith has been appointed chief of the engineering branch at Los Alamos Scientific Laboratory. **Theodore M. Benziger,** chemical engineer, and **Robert D. Fowler,** former chemis-

try professor, have been added to the staff of the laboratory.

Max Isenbergh, former general counsel of the President's Materials Policy Commission, has been appointed one of the two deputy general counsels of the Atomic Energy Commission.

Peter Debye has retired as professor of chemistry at Cornell University. The Nobel Laureate, who has received emeritus rank, will remain at Cornell to do research work.

MEETINGS

International Conference on Beta and Gamma Radioactivity—Amsterdam, The Netherlands, Sept. 1–6

American Mathematical Society, Summer Meeting—East Lansing, Mich., Sept. 3–6

American Physical Society (Division of Electron Physics)—Princeton University, Princeton, N. J., Sept. 4–6

2d International Congress on Analytical Chemistry—Oxford, England, Sept. 4–9

3d National Standardization Conference (American Standards Association)—Museum of Science and Industry, Chicago, Ill., Sept. 8–10

American Society of Mechanical Engineers, Fall Meeting—Sheraton Hotel, Chicago, Ill., Sept. 8–11

7th National Instrument Conference and Exhibit—Cleveland, O., Sept. 8–12

International Council of Scientific Unions, Joint Commission on Spectroscopy—Columbus, Ohio, Sept. 8–12

Instrument Society of America, Annual Meeting—Cleveland, O., Sept. 8–12

Joint Commission on Radiobiology—Stockholm, Sweden, Sept. 9–12

7th National Chemical Exposition; exhibit and full-day's program on "Industrial Uses of Atomic Energy" featured (Chicago Section of the American Chemical Society)—Chicago Coliseum, Chicago, Ill., Sept. 9–13

American Chemical Society, 122d National Meeting—Atlantic City, N. J., Sept. 14–19

3d Instruments and Measurements Conference and Exhibition (includes Symposium on Methods of Measurement in Nuclear Physics and Radioactivity), Royal Swedish Academy of Engineering Sciences and Association of Technical Physicists—Stockholm, Sweden, conference Sept. 22–25, exhibit Sept. 23–30

American Association for the Advancement of Science (Alaska Division)—Mt. McKinley National Park, Alaska, Sept. 22–27

American Roentgen Ray Society—Houston, Tex., Sept. 23–26

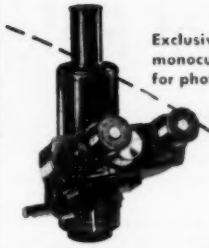
National Electronics Conference—Chicago, Ill., Sept. 29–Oct. 1

4th International Heat Congress—Paris, France, Sept. 29–Oct. 4

International Council of Scientific Unions, General Assembly—Amsterdam, The Netherlands, Sept. 30–Oct. 3

American Physical Society, New York State Section—Cornell University, Ithaca, N. Y., Oct. 17–18

4th Inter-American Congress of Radiology—Mexico City, Mex., Nov. 2–6



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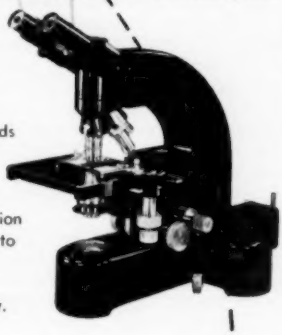

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New AEC Patent Releases

THE Atomic Energy Commission has released a new list of patents available for royalty-free, nonexclusive licensing. Applicants should apply to the Chief, Patent Branch, Office of the General Counsel, U. S. Atomic Energy Commission, Washington 25, D. C. Patents should be identified by number and title.

Ion Gage Mounting (2,594,212) C. B. Proudfoot—compact, readily disassembled mounting avoids extraneous oscillating regions.

Thermal Flowmeter (2,594,618) E. T. Booth, Jr.—readings of this flowmeter are primarily a function of mass flow rate.

Flowmeter (2,594,668) C. Mannal—electric flowmeter measures small flows of gas.

Photomultiplier Tube Circuit (2,594,703) L. F. Wouters—circuit designed for tube operation at higher-than-normal voltages. Output may directly drive auxiliary circuit.

Viewing Device for Radioactive Materials (2,594,970) G. S. Monk—device comprises an enclosed chamber, periscopic viewer, and mechanism for rotating sample.

Magnetic Contouring System (2,594,989) W. M. Powell—method of contouring the flux intensity emanating from a magnetic surface.

Universal Manipulator for Grasping Tools (2,595,134) C. M. Gordon—remote handler for radioactive materials.

Radiation Counter (2,595,550) J. A. Simpson, Jr.—high-geometry proportional counter tube having high alpha sensitivity and high beta-background tolerance.

Photomultiplier Coincidence Circuit (2,595,552) R. E. Thomas—circuit for scintillating crystal detectors.

Ionization Gage (2,595,611) K. M. Simpson, W. R. Baker, Q. A. Kerns—electronic pressure gage for regulation of ionizing current flow.

Fission Indicator (2,595,622) C. E. Wiegand—fission-fragment ionization is indicated without interference from charged-particle ionization.

Uranium-Aroyl Aldehyde Complexes and Method of Making Same (2,596,047) H. I. Schlesinger, H. C. Brown—method for synthesizing new chelate compounds of uranium with aroylaldehydes.

Ionization Chamber (2,596,080) J. R. Raper, R. E. Zirkle—Neutron- and gamma-ray-induced ionization is proportional to damage produced in human tissue.

Fluorinated Compounds and Process of Producing Same (2,596,084) P. E. Weimer—covers certain perfluorinated compounds suitable for use as lubricants.

Pocket Radiation Alarm (2,596,500) E. W. Molloy—integrating radiation exposure indicating device produces audible warning when tolerance dosage is registered.

Vibration-Measuring Device (2,596,529) H. F. Clarke—measures vibrations by means of electromagnetic-field-coupling between the device and the observed object. Amplitude of reflected microwaves measured as function of instantaneous position of observed surface.

Vibration-Measuring Device (2,596,530) H. F. Clarke—wave energy reflected back into wave guide creates varying unidirectional potential corresponding to instantaneous standing wave pattern.

Vibration-Measuring Device (2,596,531) H. F. Clarke—employs electromagnetic-field-coupling T-bridge microwave guide section.

Electronic Relay Circuit (2,596,956) L. G. Nierman—a d-c actuated relay circuit, which is sensitive, simple, stable, reliable.

Radioactive Assay Apparatus (2,597,535) E. G. Segre—shielded apparatus for assay of fissionable material. Neutron source irradiates simultaneously one or more samples of fissionable material placed in separate ionization chambers.

Insulator Bushing Seal (2,597,596) J. D. Reid—mechanical seal for stem that passes through side of evacuated chamber.

Ionization Chamber (2,598,215) C. J. Borkowski, R. H. Firminhac—for measuring alphas from radioactive dust particles collected on large sheet of filter paper.

Thermal-Neutron Detector Element (2,599,156) H. W. Bousman—cylindrical element, coated with B^{10}-enriched boron, for use as electrode in thermal-neutron detecting and counting device.

Method of Identifying Radioactive Compounds (2,599,166) A. J. Dempster—identification of constituents of a mixture is made by first separating them by charge-to-mass ratio, and then measuring radiation of each mass deposit from mass spectrograph.

Pulse-Type Transformer (2,599,182) Q. A. Kerns—low-leakage reactance pulse transformer having compositely wound primary and secondary will pass pulses without distortion and can provide any ratio of transformation.

Magnetic Peeler for Proton Synchrotron (2,599,188) M. S. Livingston—improved arrangement for deflecting particles from curved orbits.

Monitoring of Gas for Radioactivity (2,599,922) W. R. Kanne—ionization chamber for monitoring activity of a gas stream; has large ratio of field strength to voltage, and open mesh screen electrodes.

Oxidation Inhibitors of U_3O_8 (2,599,946) I. Sheft, S. M. Fried—process for inhibiting oxidation of uranium oxides when valence of uranium is less than 6.

High-Voltage Multiple-Core Transformer (2,600,057) Q. A. Kerns—has low stray capacitance and low leakage reactance, and can withstand very high voltage pulses of short duration.

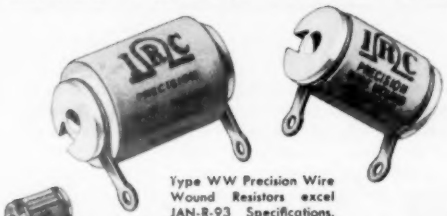
Ion Producing Mechanism (2,600,151) J. G. Backus—ion generator employs electron bombardment of solid body to be ionized.

Direct Current to Alternating Current Signal Converter (2,600,172) E. E. St. John—modulator circuit produces a-c output proportional in magnitude and corresponding in phase to difference between two d-c input signals. Can be used with single input.

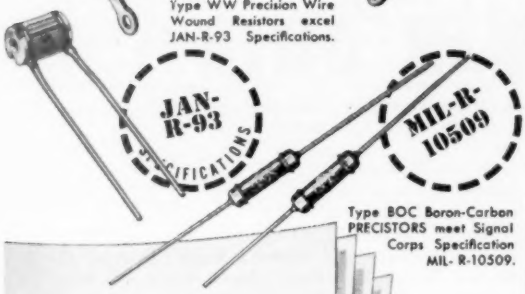
Vacuum System Leak Detector (2,600,891) S. M. MacNeille—passage of foreign gas through leak results in audible signal.

Method and Apparatus for Measuring Low Pressures and Related Conditions (2,600,936) W. G. Stone—heated Pirani resistance and variation of pressure gives harmonics of voltage drop across resistance. Amplitude of harmonic which varies with pressure gives index of pressure.

TESTS PROVE THESE NEW RESISTORS HAVE NO EQUAL FOR CRITICAL ELECTRONIC AND AVIONIC CIRCUITS

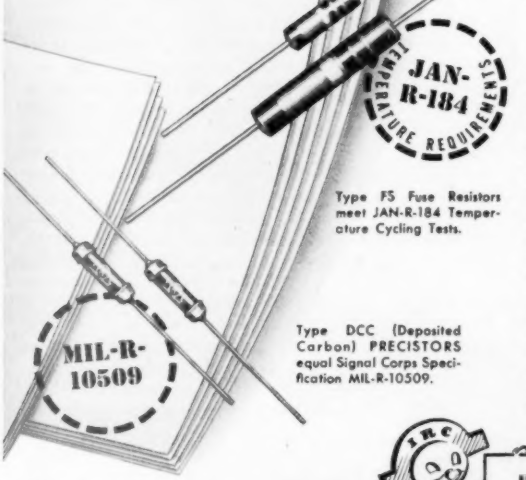


Type WW Precision Wire Wound Resistors excel JAN-R-93 Specifications.



Type BOC Boron-Carbon PRECISTORS meet Signal Corps Specification MIL-R-10509.

TEST RESULTS



Type FS Fuse Resistors meet JAN-R-184 Temperature Cycling Tests.

Type DCC (Deposited Carbon) PRECISTORS equal Signal Corps Specification MIL-R-10509.

Where an Armed Forces or Industrial specification sets up hard-to-meet requirements—*beat* them with these newly developed IRC resistors! Unbiased comparative tests *prove* they have no equal in reliability and stability.

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	Original Resist.	1st Cycle % Chge	2nd Cycle % Chge	3rd Cycle % Chge	4th Cycle % Chge	Resist. at End of 100 hrs. load	Total % Chge	% Chge from Last Temp. Cycle to End of 100 hrs. load %	Resistance Chge at End of 100 Hrs. Load only % (no cycling)
1	100,010	+.04	+.04	+.05	+.05	100,050	+.04	—.01	100,040 —.02
2	100,000	+.03	+.04	+.03	+.05	100,060	+.06	+.01	100,000 0
3	100,000	+.01	+.02	+.02	+.05	100,000	0	+.05	100,050 —.02
4	100,000	+.02	0	+.02	+.02	100,000	0	—.02	100,040 —.01
5	100,010	+.03	+.04	+.04	+.05	100,000	0	—.05	100,030 —.03
6	100,000	0	+.03	+.04	+.04	100,100	+.1	+.06	99,980 0
7	100,000	+.04	+.05	+.04	+.04	100,070	+.07	+.03	100,000 0
8	100,000	+.03	+.05	+.05	+.05	100,050	+.05	0	100,000 0
9	100,000	+.04	+.03	+.05	+.04	100,010	+.01	—.03	100,050 0
10	100,000	+.02	+.02	+.02	+.04	100,010	+.01	—.03	100,000 0
11	100,000	0	+.01	+.01	+.03	100,000	0	—.03	

Severe cycling and 100-hour load tests resulted in virtually zero changes in resistance. Other rigid tests prove Type WW's high mechanical strength, freedom from shorting, resistance to high humidity.

New Type BOC Boron-Carbon PRECISTORS offer tremendous advantages in military electronic equipment—radar, gunfire control, telemetering, communications, computing and service instruments. Type BOC's combine high accuracy and long-time stability, reduce temperature coefficient of conventional deposited carbon resistors, replace high value wire wound precisions at substantial savings in space and cost.

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LETTERS

Nuclear-Power-Plant Costs

DEAR SIR:

We read with considerable interest the article entitled, "Economics of Steam-Temperature Selection in Nuclear Power Plants," by R. D. Elliott in the February '52 NUCLEONICS. Mr. Elliott has done a thorough job of analysis on the available data, and his conclusions are no doubt applicable to conventional power plants. We question, however, that these conclusions based on conventional plant costs can be extended to a power plant using heat from a reactor.

Specifically, we question the conclusion that "If the fuel is free or if its cost is paid by funds not chargeable to the power station, it is most economical to build and operate a plant at about 600° F to 800° F." This conclusion probably applies to the data studied, but it should not be assumed that nuclear-power-conversion-system costs vary in the same manner as conventional-plant costs.

Since fuel costs are not a factor, only operating and investment costs are considered in a nuclear-power-conversion plant. It is difficult to see the reason for much variation in operating cost with increased steam temperatures and pressures only. This variation, if any, is likely to be small and is extremely difficult to predict.

Plant investment is probably the most significant factor in determining the optimum steam conditions for a nuclear-power-conversion plant. It is necessary, of course, to assume the same rate of depreciation and the same load factor for plants at all steam conditions. Data on cost variations of conventional plants are not applicable to nuclear-power conversion mainly because of the difference in steam-generator cost. In a conventional plant, the boiler and building to house it represent a larger proportion of the total plant cost than a liquid-to-liquid type of boiler in a nuclear power plant. Furthermore, the variation in cost with temperature is very likely to be different for each case.

Conventional boiler materials and construction procedures are apt to be more costly at higher temperatures and pressures. In the case of a nuclear-power-plant boiler, the variation in cost with temperature is likely to be less because the same materials and stringent manufacturing procedures are required for handling the heat-transfer liquid over the range of temperature from 600° F to 1,000° F.

This factor makes it questionable to apply cost data on conventional plants to nuclear-power-conversion plants.

There are, no doubt, other requirements not usually encountered in power plant economics which are dictated by reactor considerations and which have a significant effect on the economics of the particular application. We believe that only a study based upon preliminary designs, at least, can be used to establish optimum conditions.

Another point not clearly expressed is the effect of plant efficiency on investment cost. For a fixed reactor heat output, it follows that a larger output of salable kilowatt-hours results from the more efficient higher temperature plants. If the investment cost increases less sharply with steam temperature for a nuclear-power-conversion plant than for a conventional plant, it is possible for the ratio of investment cost to kw-hr output to decrease with increasing steam temperature in the range of 600° F to 1,000° F. From preliminary designs and cost estimates we have made of nuclear-power-conversion plants, we believe this to be the case.

T. TROCKI and J. D. SELBY
Knolls Atomic Power Laboratory
General Electric Company
Schenectady, New York

Author's Reply. I would like to thank Messrs. Trocki and Selby for their interest and comments. Their criticism is centered on their contention that the cost of nuclear-heated boilers does not vary greatly with steam temperature.

Current proposals for such boilers are based on meager or no operating experience, and there is a tendency for the equipment to be overdesigned. It is easier to add extra margin at the low end of the temperature range; this has a leveling effect on the cost curve. When several plants have been built and run for a while, it will probably be found that the variation of costs with steam temperature more closely follows that of conventional boilers.

An important variable in liquid-heated boilers which is of minor importance in fired boilers is the available temperature difference for heat transfer. If the reactor temperature is limited, a few degrees' increase in steam temperature may require that the boiler size be increased greatly.

A complete determination of the economic optimum steam temperature would necessarily include the effects of operating temperature on the cost and performance of the reactor, but a discussion of this was beyond the scope of the article.

A noteworthy item in the letter from Trocki and Selby is that the cost of the boilers in a nuclear power plant is expected to be less than in conventional plants. It is hoped that any additional data on the cost of nuclear-heated boilers and related equipment will be published when it is available.

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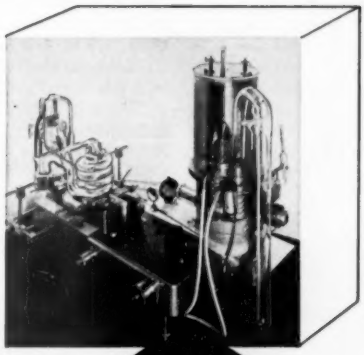
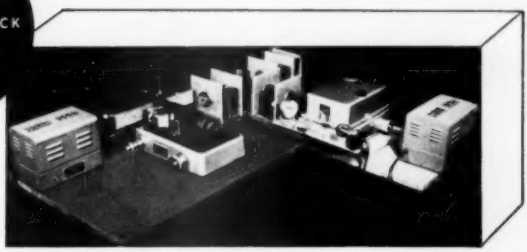


American Cyanamid Company—Monochromator with Raman spectrometer attachments built by Stamford Research Laboratories.

TYPICAL BUILDING BLOCK ASSEMBLIES



Fordham University—Two-monochromator set-up for testing reaction of human eye to light intensity developed at psychology laboratory.

Sloan-Kettering Institute—Monochromatic light source for microscope illumination used in cancer research to show UV absorption.

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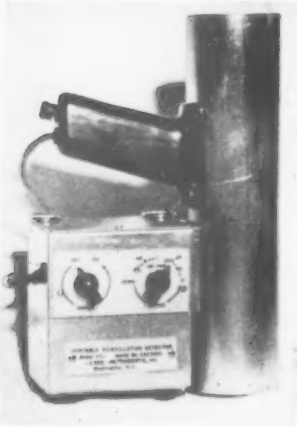


Gamma Detector

La Roe Instruments, Inc., 743 Investment Building, Washington 5, D. C. The model FV1 portable scintillation detector, designed to measure gamma activity, has full-scale ranges of 0.01, 0.05, 0.25, 1, 5, and 25 mr/hr, with a linearity of ±5% up to 5 mr/hr. The gun section, which contains a magnetically shielded 5819 photomultiplier and permanently sealed sodium iodide crystal, has been waterproofed. Battery life is greater than 100 hr; the instrument has been ruggedized for field use, and has an illuminated dial.

Gamma Dosimeter

Magnex Corp., 90-28 Van Wyck Expressway, Jamaica 18, N. Y. The Atometer chemical dosimeter is designed for civil defense use. The color change of an acid-sensitive dye is matched with a color chart calibrated in roentgens on the cover of the plastic housing. Dosages of 0–600 r can be determined within ±50% of the true value. The color remains constant for several weeks for exposures up to 400 r; readings must be taken within 4 hr after exposure to 600 r. Temperature and radiation-rate dependence are negligible.

Photomultiplier Attachment

Beckman Instruments, Inc., South Pasadena, Calif. This photomultiplier attachment, for the model DU spectrophotometer, is stated to provide increased resolution and an amplification from 100 to 1,000 times that of the standard ultraviolet-sensitive phototube. The 1P28 multiplier tube and a load resistor are used for measurements below 600 mμ; the red-sensitive phototube plus another load resistor is used above 600 mμ. An auxiliary battery box supplies the required additional power to the photomultiplier tube.

Decade Scaler

Nuclear Measurements Corp., 3339 Central Ave., Indianapolis 5, Ind. The model DC-1 scale of 1,000, comprising three direct-reading plug-in decade units, has a maximum counting rate of 10^6 cpm and a resolving time of 2 μsec. A six-digit register totals up to 10^7 counts; an automatic timer provides continuous timing up to 55 min with an accuracy of 0.2 sec. The 500–1,500-volt regulated power supply is continuously variable; a 650–2,500-volt supply is optional. Connection is provided for coincidental elapsed-time indication.

Remote Handler

Tracerlab, Inc., 130 High St., Boston 10, Mass. The 6-ft E-32 remote magnetic handler, constructed of aluminum tubing, weighs 2 lb, 15 oz, and has a 12-in., chrome-plated, flexible gooseneck with a stainless-steel tip. A permanent Alnico magnet is encased in the tip and a cast-aluminum grip is depressed to withdraw the magnet from the tip to release the source.

Radioactive Organs

Nuclear Instrument and Chemical Corp., 223 W. Erie St., Chicago 10, Ill. Carbon-14-labeled organs and tissues from rats fed on a diet of labeled compounds will be available as soon as sufficient interest has been shown. Some of the organs and tissues will be: adrenals, bladder, blood, brain, eyes, heart, kidney, liver, pancreas, skeleton, skin, spinal cord, spleen, teeth, testes, cancer tissue, and miscellaneous tissue.

Pulse Transformer

Berkshire Laboratories, 538 Beaver Pond Rd., Lincoln, Mass. The type PT-1 pulse transformer is designed for use in microsecond and fractional mi-

crosecond ranges. Its windings comprise six sections, of which two pairs are connected in series and the other two sections are individually connected to base pins. The connection diagram is on the end disk of each unit.

Power Supply

Huggins Laboratories, 790 Hamilton Ave., Menlo Park, Calif. This single-pulse power supply, for use with mercury arc lamps, can be used in high-speed photography, cloud-chamber studies, and other cases where instantaneous repetitive flashes are required. With the mercury arc lamps, the light output per flash is about 160 lumens. Maximum repetition rate is one flash per 10 sec. The unit is capable of delivering a 4,000-volt 10-μsec pulse from a 0.5-μf capacitor. The capacitor discharge is actuated either manually or through terminals which allow connection of an extension line or synchronizing circuits from other equipment.

Lead Beakers

St. George Mfg. Co., 5608 Milwaukee Ave., Chicago 30, Ill. Beaker No. 100-30, with inside dimensions of $1\frac{7}{16}$ in. diameter and $2\frac{3}{4}$ in. high, and No. 100-10, $1\frac{1}{16}$ in. diameter and 2 in. high, are made of $\frac{1}{2}$-in. cast lead. A raised lip prevents the cover from slipping, and the beakers are claimed to be easily decontaminated.

Chopper Amplifier

Keithley Instruments, 3868 Carnegie Ave., Cleveland 15, Ohio. The model 300 universal chopper amplifier has a maximum gain of 800,000, frequency response of 0–500 cps, input impedance of 1 megohm, and noise and drift within 25 μv, or 2% of full scale. The amplifier works with most pen recorders, recording galvanometers, and cathode-ray oscilloscopes.

Surface Pyrometer

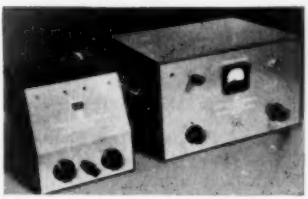
The Pyrometer Instrument Co., Inc., Bergenfield, N. J. The Pyro surface pyrometer is available with 14 types of thermocouples and rigid or flexible extension arms which are interchangeable without adjustment or recalibration. Readings may be taken directly with automatic cold-end compensation. Models 30 to 34 cover temperature ranges from 0–300° F to 0–1,200° F; Centigrade calibration is also available. The thermocouples are designed for convex and rotating surfaces, flat surfaces, and metallic surfaces; thermocouples for sub-surface measurements are designed for plastics, rubber, semi-fluids, liquids, gases, and molten soft metals.

Temperature Control

Technical Equipment Co., 4348 San Pablo Ave., Emeryville 8, Calif. The Electron-o-Therm temperature controller, employing a resistance thermometer regulator hermetically sealed in Pyrex, is designed for use in constant-temperature baths, ovens, and related thermal equipment. The controller incorporates a bridge circuit and vacuum-tube amplified controller. The range is −30 to 225° C with a regulation limit of 0.001° C. Heater capacity is 1,700 watts. The original precision and reliability are claimed to be retained indefinitely.

Capacitors

Sprague Electric Co., 259 Marshall St., North Adams, Mass. The types B20, B21, B22, and B23 hermetically sealed ceramic capacitors are rated for voltages of 500, 1,000, and 1,500 volts, d-c. They are claimed to have a possible controlled capacitance tolerance within ±1% and temperature coefficient tolerances within ±10 ppm per °C. For less critical applications, the usual tolerance on temperature coefficient is ±30 ppm or ±15% of the nominal temperature coefficient, whichever is greater.



Magnetometer

Laboratory for Electronics, Inc., 75 Pitts St., Boston 14, Mass. The model

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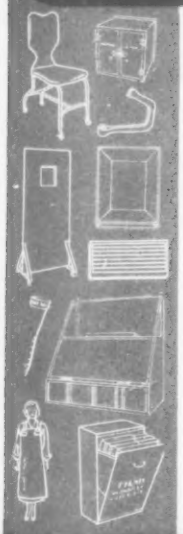
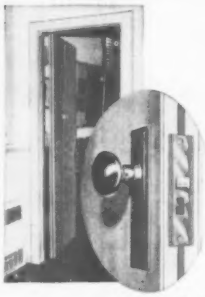


LEAD-LINED DOORS



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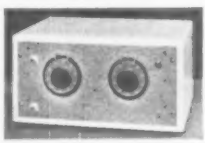
For pulse height analysis

Atomic's Single Channel Model 510 gains wide acceptance



The Model 510 makes possible studies of amplitude distribution of electrical pulses whose amplitudes fall in the range from zero to 100 volts. When used with a linear or calibrated particle detecting device, a linear amplifier, and a scaler or other counting means, the Model 510 enables laboratories to study the energy distribution of nuclear particles. The adjustable channel or "window" can be set from zero to 7 volts wide, and located at any voltage level between zero and 100 volts.

Atomic's **New** Fast 20-Channel Pulse Height Analyzer

Model 520 allows data to be taken and recorded in 20 channels simultaneously. Provides spectrum data on long-life isotopes in less time and on short-lived isotopes with fewer decay corrections. Model 520 can be adapted readily for gathering data on distribution of fog particle sizes, and on distribution of radar amplitudes and similar distribution studies. Channel width—0.8 volt (approx.) for each channel at the output of the built-in linear amplifier. Overall resolution time—2.4 microseconds, minimum, for two pulses not falling in the same channel.

For details on these and other Atomic instruments, write for new illustrated, indexed catalog.

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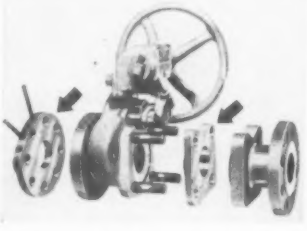
101 magnetometer, which operates by the measurement of proton resonance and the nuclear resonance of Li^7, determines field strengths of 300–25,000 gauss, covered by a frequency spectrum of 1.18–34 Mc. The width of modulation sweep may be varied from 1.6 to 16 gauss. The equipment's use is limited to the measurement of magnetic fields whose homogeneity is at least 1 part in 500 for proton resonance and 1 part in 5,000 for lithium resonance over the dimensions of the sample to be detected. The sample material has an area of approximately $\frac{1}{3}$ cm².

Gas Analyzer

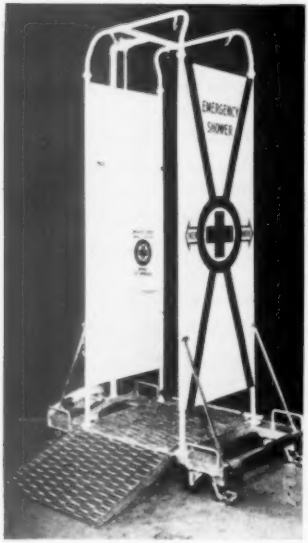
Liston-Becker Instrument Co., Inc., P. O. Box 1110, Stamford, Conn. These infrared absorption gas analyzers may be used as warning devices for toxic atmospheres, for study of respiratory gases, and for combustion study and control. Most gases can be analyzed, with the exception of N_2, H_2, and O_2. Response speeds of 0.1 sec for 90% complete response can be supplied. The model 16 CO_2 analyzer has a speed of response of 0.1 sec for 90% and a range of 0–15% CO_2. Absorption cells for ranges from 0–3% to 0–30% can be furnished. It is claimed that a maximum error of 0.1% CO_2 may be obtained with ease. Output is 5 ma across 500 ohms, 16 volts above ground.



Heated Valve

Okadee Co., 332 S. Michigan Ave., Chicago 4, Ill. This electrically-heated valve keeps valve mechanisms clear of frost and ice in liquid carbon dioxide

lines at temperatures as low as −110° F. Single-disk valves require the heating element at right in the illustration; double-disk valves can be equipped with both elements illustrated. Valve sizes from 2 in. to 6 in. are available, with pneumatic, hydraulic, solenoid, or manual control. Heating elements can be provided for either 110- or 220-volt operation, with inputs ranging from 400 to 3,000 watts per unit.



Portable Shower

Logan Emergency Showers, Inc., P. O. Box 111, Glendale, Calif. This portable emergency shower, made of corrosion-resistant red brass, directs sprays from four overhead outlets, two sprays for eyes and face, four bottom sprays that direct streams upward, and four sprays for the feet. Couplings for connection to the water system and adjustable truck stops for holding the unit in position are supplied. The shower can be entered from either of two sides; the valve for turning on the water is operated by a swinging gate that is activated by pressure applied by the body of the user.

INDUSTRY NOTES

▶**Beckman Instruments, Inc.,** South Pasadena 5, Calif., has added another building to the thirteen it already occupies, to house a new special products division for the development of new types of instruments and for the personnel department. The special

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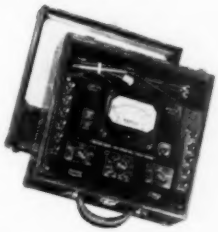

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WESTON *Instruments*

products division, headed by J. F. Bishop, is devoted to the manufacturing and testing of special instruments brought to it by industrial organizations.

▶**Len J. Wong,** 3259 Madison Rd., Cincinnati 9, Ohio, is setting up an office as a consulting engineer specializing in nuclear and precision instruments.

▶**Radiation Counter Laboratories, Inc.,** 5122 W. Grove St., Skokie, Ill., has appointed Dr. Freidrich Schwarz as director of mechanical and design engineering.

▶**Bjorksten Research Laboratories, Inc.,** Madison Wis., has formed the Bjorksten Radiochemicals Division to be directed by Howard L. Gottlieb.

▶**Nuclear Instrument and Chemical Corp.,** 223 W. Erie St., Chicago 10, Ill., was recently named on the new-member list of the Chicago Association of Commerce and Industry.

▶**Glass Engineering Laboratories,** Belmont, Calif., has opened a branch location at 6309 S. Broadway, Los Angeles, for the distribution of glass apparatus and piping.

▶**Kinney Mfg. Co.,** Boston, Mass., has appointed William B. Mills as Philadelphia district manager.

LITERATURE AVAILABLE

Pulse control units. Bulletin describes pulse generators, flip-flops, coincidence detectors, and other pulse controls, and power supplies and controls. *Control Instrument Co., Inc., 67 35th St., Brooklyn 32, N. Y.*

Transformers. Bulletin R-31 explains principles and applications of differential transformers. *Automatic Temperature Control Co., 5200 Pulaski Ave., Philadelphia 44, Pa.*

Germanium diode. Bulletin B-46 gives data on type GCD-1 high-back-resistance germanium diode. *Berkshire Laboratories, 538 Beaver Pond Rd., Lincoln, Mass.*

Laboratory supplies. "What's New for the Laboratory," No. 15, lists instruments, chemicals, and glassware. *Scientific Glass Apparatus Co., Inc., Bloomfield, N. J.*

Glossary. List defines 58 words commonly used in the radioactive measurement field. *Radiation Counter Laboratories, Inc., 5122 W. Grove St., Skokie, Ill.*

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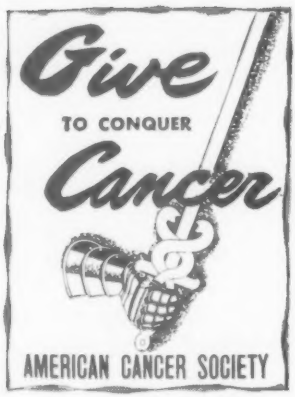

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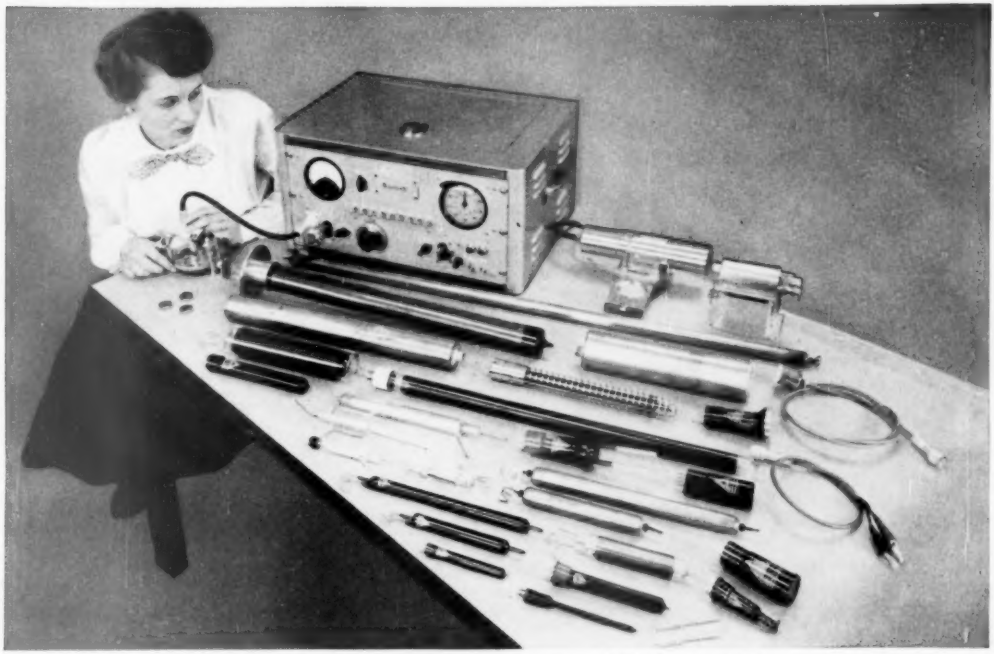

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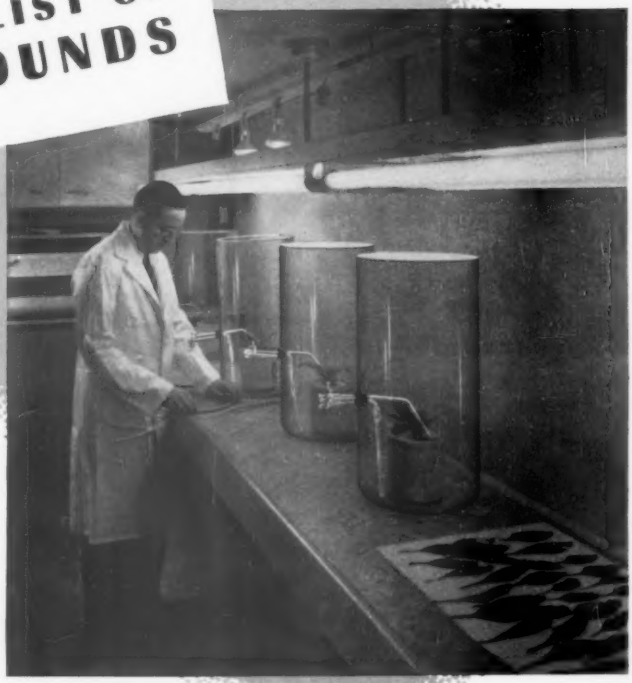

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